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SUMMARY REPORT
TACIUK PROCESSOR

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CanonieEnvironmental

SUMMARY REPORT
TACIUK PROCESSOR

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SUMMARY REPORT TACIUK PROCESSOR

1.0 INTRODUCTION

The Taciuk Processor is an anaerobic thermal processor developed in Canada by a subsidiary of Underwood McLellan Associates (UMA). The technology development was funded by and is owned by the Alberta Oil Sands Technology and Research Authority (AOSTRA), an agency of the Government of the Province of Alberta.

The processor was developed under the synthetic fuels program in the mid-1970s and is proposed as a large-scale process for economically separating oil from oil sands and oil shale. Early work in the development of the Taciuk Processor was conducted on oil sands processing and includes the design of units for processing 100 to 1,000 tons per hour (TPH).

Recent work using the 5 TPH AOSTRA pilot plant in Calgary, Canada includes the processing of soils containing waste oils. In addition, many bench level tests have been completed on soil/oily waste samples from sites in both the United States and Canada.

This report summarizes the past work on the bench-scale and 5 TPH pilot unit, describes the general process, and reports on a preliminary design for a net 5 TPH processor to treat soils at the Waukegan Harbor Site (Site).

2.0 SUMMARY

The proposed process design is based on the results of bench-test work and previous environmental sampling at the Site. The bench-test work results are:

- a) PCB levels are reduced to below normal detectable limits of 0.1 ppm in the sand and muck treated by the bench-scale processor.
- b) The test results indicate that the aroclor composition of the PCBs does not change due to processing.

The Processor will treat an estimated 16,000 cubic yards (cy) of soils and sediments consisting of approximately 7,500 cy of sand and 8,500 cy of muck (about 20,000 wet tons) over a period of six to nine months. Using the thermal processor, the soil and sediment containing PCBs will be reduced in volume by about 87 percent and the PCBs will be separated for final destruction at an off-site permitted TSCA incinerator.

3.0 DESCRIPTION OF THE PROPOSED PROCESS

The Taciuk process will separate the feed product into water, oil, and dry sand and silt. The water from the Taciuk process will be treated in the water treatment plant provided for the in-place containment (IPC) construction activities. Over 97 percent of the PCBs will go to off-site disposal. The processed soils will contain less than 50 mg/kg of PCB, and will be placed in one of the IPC enclosures. The anaerobic conditions in the Taciuk Processor will allow PCBs to separate from the solids and water without forming intermediate oxidized products such as dibenzofurans and dioxins.

3.1 Equipment Selection

Figure 1 presents a schematic diagram of the Taciuk Processor. The processor contains separate preheat, reaction (or pyrolysis), combustion, and cooling zones. Low temperature volatiles such as water and light oils are extracted in the preheat zone at temperatures up to 500°F. Heavy oils and PCBs are volatilized in the reaction zone at temperatures of 700°F to 1,100°F under anaerobic (oxygen depleted) conditions. The water and oil products are removed from the processor and condensed and collected in separate gas and vapor train equipment. Depending on the feed composition, some thermal cracking occurs in the reaction zone creating light oils and coke (char). This coke is burned in the combustion zone at 1,100°F to 1,200°F to provide part or all of the heat requirements of the process. Part of the hot sand in the combustion zone is recycled back to the reaction zone to provide the heat source for pyrolysis. The remaining sand is cooled for discharge by heating the incoming sand in the preheat zone by thermal conduction. The anaerobic condition in the reaction zone is maintained by sand seals located between the preheat zone and the reaction zone and between the reaction zone and the combustion zone. The Taciuk process is protected under United States Patent No. 4,306,961. A copy of the patent is enclosed in Appendix C.

Substantial work has been performed in developing this technology to its present level of efficiency, including bench testing, pilot testing at rates between 3 TPH and 5 TPH, and engineering and design studies for units with capacities of 100 TPH and 1,000 TPH. The testing and pilot work have established a broad database for the performance of the processor with a variety of feedstocks. A summary of the background of the development of the Taciuk Processor is presented in Appendix A.

In the field of waste treatment, the materials listed in Table 1 have been tested at the bench and pilot (5 TPH) scales. Because of the variety of materials tested and the demonstrated scale relationships between bench and pilot tests, bench-test work is adequate for a preliminary design and costing of a Taciuk Processor for the separation of PCBs.

4.0 PRELIMINARY PROCESS DESIGN

This section of the report presents the preliminary process design. The database on which the design is based incorporates the results of bench-scale testing and of previous environmental sampling and analysis at the site.

4.1 Sampling for Bench-Scale Tests

On November 19, 1987, a four-gallon sample of organic silt and a four-gallon sample of uniform fine sand were recovered from the Crescent Ditch in the immediate vicinity of the former outfall pipe. Figure 2 shows the approximate sample location. The samples were recovered in a vertical profile, with the organic silt overlying the fine sand. The organic silt is an oily bottom sediment with a high water content. The organic silt contains leaves and other partially decomposed organic matter. The fine sand sample is of uniform gradation, black color, and wet. Water in the fine sand sample separates easily and was decanted prior to shipment.

4.2 Design Basis: Bench-Scale Test Results

Bench-scale tests were performed on the sand and muck samples. The tests indicate PCBs may be totally removed from the sand and muck materials by the Taciuk Processor. A detailed compilation of the results of the bench-scale test work is presented in Appendix B.

Thermal gravimetric analysis (TGA) runs were made on small aliquots from the sand and muck samples to determine at what temperatures volatiles would evolve. Figures 3, 4, and 5 present the results of these tests. The weight loss curves show the initial evaporation of water at temperature ranges between 80°C and 200°C (175°F and 400°F) and a second evaporation of oil (PCBs) at temperatures between 200°C and 360°C (400°F and 720°F). A third weight loss occurs at about 750°C (1,380°F), but this is considered

to be a mineral decomposition reaction which will occur beyond the temperature reached in the Taciuk Processor.

Following the TGA analysis, four samples of muck and/or sand were tested in the batch test equipment which is shown schematically on Figure 6. In the case of the sludge, which was mostly water, a silica sand charge was added to the bench-scale unit to simulate the hot sand recycle which will be used in the commercial pyrolysis unit.

Table 2 shows the analyses of the products from the bench tests. A low temperature (200 to 300°F) vapor product was produced and condensed during the initial stages of heat up. This product consisted mostly of water, with finely suspended solids and some light oils and contained less than two percent of the PCBs accounted for in the product. At higher temperatures (500 to 750°F), an oil product was produced which contained some water and most of the PCBs. The charred solid product did not contain detectable levels of either PCBs or 2,3,7,8 dioxins.

A loss on ignition (LOI) measurement was made by burning the charged product from each test. This test determines how much heat value can be achieved in the processor by burning the residual coke produced in the pyrolysis zone. In the bench tests, the LOI was less than 3 percent indicating supplemental heat will be required to provide the heat requirements of the commercial unit. A sample of burned material was analyzed for PCBs and 2,3,7,8 dioxin. The concentrations of PCB and 2, 3, 7, 8 dioxin were below detection limits.

4.3 Design Basis: Previous Environmental Sampling

Previous site sampling indicates a high degree of variability in PCB level over the volume of soils designated for processing. As a conservative approximation for preliminary design of the processor and its vapor recovery systems, the average concentrations of PCB were weighted towards the samples with higher concentrations. The PCB concentrations for the

Slip No. 3 soils are based on the environmental database for muck and sand from Slip No. 3. The PCB concentrations for the north property soils are assumed to be equal to the results from the bench-scale test samples.

4.4 Design Database

The volume of sand and muck in each area is from the Work Plan for the IPC remedial action. The moisture, oil, and solids content of the sand and muck have been calculated from the samples taken at the Crescent Ditch site. This data has been combined with the results of the bench-scale test work to estimate the amounts and the average feed compositions of sand and muck which will be fed to the processor. Tables 3 through 5 summarize the data upon which the preliminary design is based.

The database is not extensive in terms of characterizing the weight and physical composition of the anticipated feed. The assumptions, however, are a reasonable preliminary interpretation of the data.

4.5 Treatment Concept

A preliminary treatment concept has been prepared from the results of the bench-scale testing. Figure 7 shows a schematic diagram of the process steps.

The process concept assumes the excavated sand will be stockpiled and drained, and the sludge will be stored in a containment pond where dewatering will occur. The stockpiled sand will be fed to the processor through a feeder to minimize air entrainment in the feed and prevent entry of air to the preheat chamber. Sludge or muck will be excavated from the pond using an end loader or slurry pump and injected into the processor with the sand feed.

The low temperature vapor product from the preheat zone will be condensed to remove water, volatile organics, and dust from the gas streams. The

condensed mixture will be separated in an API oil separator. Light oil will be skimmed from the tank and will be mixed with the PCB product for disposal. Following oil removal, the water and fine sand mixture from this tank will be pumped to the IPC water treatment plant which will consist of sand filtration and liquid phase activated carbon. The water treatment plant will remove suspended solids and organics prior to surface or sanitary sewer discharge of the product water.

The high temperature vapor product from the reaction zone will be condensed and stored in tanks within a secondary containment. Sufficient capacity will be provided to hold 10,000 gallons of oil production allowing sufficient storage capacity to avoid interrupting operations. The oil will be periodically pumped out and hauled off-site for disposal by others.

The solid product discharge from the processor will be sampled with a split sampling device for a daily composite representing about 100 tons of product. The processed soil will be backfilled in the west IPC cell after sampling to verify PCB removal.

4.6 Preliminary Engineering, Design, and Equipment Specifications

Figure 8 presents a process flow diagram (PFD) for the process. Table 6 presents an estimate of the amounts of feed and products for the selected base case. Table 7 presents a list of the major equipment to be used in the process.

The design is most sensitive to the volume of water, oil, and fines in the feed. Increasing the volume of water, oil, or fines in the feed reduces the throughput rates for the processor. For example, the processor needs sand to provide the seals and the heat transfer medium. If the excavation procedure does not provide sufficient sand, borrow sand will be required reducing throughput rates. The heat balance on the processor and the sizing of the product collection systems depends on the content of water and oil in the feed. If the design amounts are exceeded by a large margin,

borrow material may be required to reduce the liquids content of the feed, or lower muck feed rates may be required to meet the heat capacity limitations of the process system. Both of these factors would result in decreased processing rate.

To overcome these potential problems, the processor will be designed to treat seven to eight TPH of material at the design conditions. This sizing will ensure that the separation may be completed in a six- to nine-month period at a low flow rate of five TPH. If the higher throughput rates are achieved, treatment of the sands and muck may be accomplished within six months.

Table 6 shows a significant volume of light oil (non-PCB oil) in the extracted oil product. Comparing the PCB concentration in the sand and muck oil products listed in Table 2, indicates the light oil comes mainly from the muck. The light oil may be separated from the PCBs in a fractionating column in the process vapor train. Burning this oil in the processor combustion zone would reduce the external heat requirements of the process and reduce the volume of oil requiring disposal by as much as 60 percent.

4.7 Pilot Plant Test Work

A pilot test run is proposed in the 5 TPH plant located in Calgary, Alberta. The purpose of the pilot test will be to demonstrate the process and to collect information on product quality and process emissions. The pilot test will also be used to assess the feasibility of separating the light oil from the PCBs.

Because of the difficulty in shipping soils known to contain PCBs across the United States/Canadian border, it is proposed that the pilot test be run on sand samples spiked with PCB at the approximate concentrations expected at Waukegan Harbor. The proposed procedure will be to establish a hot circulating sand charge in the 5 TPH pilot processor, then inject

liquid PCBs into the system on a short-term basis. This approach will enable emissions and product quality data to be collected under the anticipated operating conditions. A separate plan for the pilot test will be completed and a pilot test date scheduled by the end of February, 1988.

TABLES

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TABLE 1

WASTE MATERIALS TESTED

	<u>Type of Material</u>	<u>Hydrocarbons (Percent)</u>	<u>Water (Percent)</u>	<u>Solids (Percent)</u>
Bench Tests:				
McColl Site	Acid Alkylate Sludge	20	40	40
McKin Site	Oil Contaminated Soils	3	12	85
	API Separator Sludge	20	55	25
Wyoming Exp	Trash Oil Pits	10	68	12
Amoco Refinery	Sludge Ponds	11	57	32
Full Scale Test Runs:				
Texaco Refinery	Contaminated Soil	3	12	85

TABLE 2

PCB ANALYTICAL DATA ON FEED AND PRODUCTS FOR T1011 AND T1012⁽¹⁾

<u>Sample</u>	<u>T1011</u>	<u>T1012</u>
Waste Sample	Muck	Sand
Analysis #1	61,335	26,437
Analysis #2 ⁽²⁾	16,866	28,900
Decant Water		563
Retort Water		
Oil	50,877	68,861
Water	70	114
Solids	5,492	10,223
Retort Oil		
Oil	235,308	959,170
Water	16	12
Solid Char	Less than 0.1	Less than 0.1
Burnt Solids	Less than 0.1	Less than 0.1

NOTES:

(1) Sand analyses are mg/kg on a wet basis sludge and liquid analyses are mg/l.

(2) Reruns made on feed because of poor material balances on PCB.

TABLE 3

ESTIMATED QUANTITIES OF
EXCAVATED MATERIALS

<u>Location</u>	<u>Material</u>	<u>Yards</u>	<u>Tons</u>
Slip #3	Sand	1,500	2,230
	Muck	7,500	8,100
North Property	Sand	6,000	8,910
	Muck	1,000	1,080
Totals	Sand	7,500	11,150
	Muck	8,500	9,180
		16,000	20,320

NOTE: Bulk density of sand is assumed to be 110 pounds per cu ft. Bulk density of muck is assumed to be 80 pounds per cu ft.

TABLE 4

COMPOSITION OF SAND AND MUCK EXCAVATED
FROM SLIP #3 AND NORTH PROPERTY GROUNDS

<u>Material</u>	<u>Component</u>	<u>Composition % by Weight</u>	<u>Bulk Density lb/cu ft</u>
Sand	Oil	3.9	40
	Water	14.3	
	Solids	81.8	
Muck	Oil	17.4	80
	Water	54.2	
	Solids	28.4	
Feed Mixture	Oil	11.3	94
	Water	36.2	
	Solids	52.5	

NOTE: These compositions assume the sand material has been stockpiled and drained and the muck material has been partly dewatered following excavation.

TABLE 5

EXPECTED AMOUNT OF PCB PRODUCED
BY PROCESSING

<u>Location</u>	<u>Tons (Wet)</u>	<u>PCB mg/kg (Wet Basis)</u>	<u>Tons of PCB</u>	<u>Gallons⁽¹⁾ of PCB</u>
Slip #3				
Sand	2,230	38,349	85	15,680
Muck	8,100	39,179	317	58,475
North Property	<u>9,990</u>	<u>30,325</u>	<u>303</u>	<u>55,895</u>
Total	20,320		705	130,050

(1) Assumes a specific gravity of 1.3.

TABLE 6

PRELIMINARY MATERIAL BALANCE OF FEED AND PRODUCTS
(BASIS 5 TPH, 20 HRS PER DAY)

Feed:	100 tons per day
Sand	55
Muck	45
Products:	
Light oil to disposal	5.8 tons per day/1,545 gallons per day
PCB to disposal	3.5 tons per day/640 gallons per day
Gas to recycle	2.0 tons per day/75 SCFM
Water to treatment plant	36 tons per day/7 gpm
Ash to disposal	52 tons per day
Flue gas	10,000 SCFM

TABLE 7

PRELIMINARY LIST OF MAJOR EQUIPMENT ITEMS

- | | |
|----------|---|
| Item 1) | 36 cy feed storage bin system with weigh feeders and enclosed conveyor system. |
| Item 2) | Slurry feed delivery system consisting of double slurry pumps and feed lines. |
| Item 3) | Processor rotating kiln assembly including mounting frames, mechanical drives, and instrumentation. Kiln dimensions are expected to be 12 ft diameter by 30 ft long. |
| Item 4) | Low temperature stream condensing system including hot cyclone, heat exchanges, liquid gas/oil water separators and water pumps. |
| Item 5) | High temperature volatiles condensing and collection systems including hot gas cyclone, possible fractionating tower, condensers, and oil pumps. |
| Item 6) | 10,000 gallon tank farm complete with berm enclosure to contain the contents of all tanks. |
| Item 7) | Flue gas scrubbing system having a capacity of 10,000 - 12,000 ACFM, consisting of a hot gas cyclone, a baghouse, and a wet scrubber with associated tankage and pumps required to run closed circuit scrubbing using caustic or other chemicals. |
| Item 8) | Portable activated carbon air abatement system with a capacity of 12,000 ACFM and an initial charge of 15,000 pounds of activated carbon. |
| Item 9) | Separate electrical motor control control package and control room containing all input/output requirements for plant operations monitoring, control and emergency shutdown. |
| Item 10) | Circulation pumps and fans required to supply cooling water, transport liquids, and maintain design operating pressures in the Processor. |

NOTE: The processing system will require a footprint space of 100 ft by 150 ft.

FIGURES

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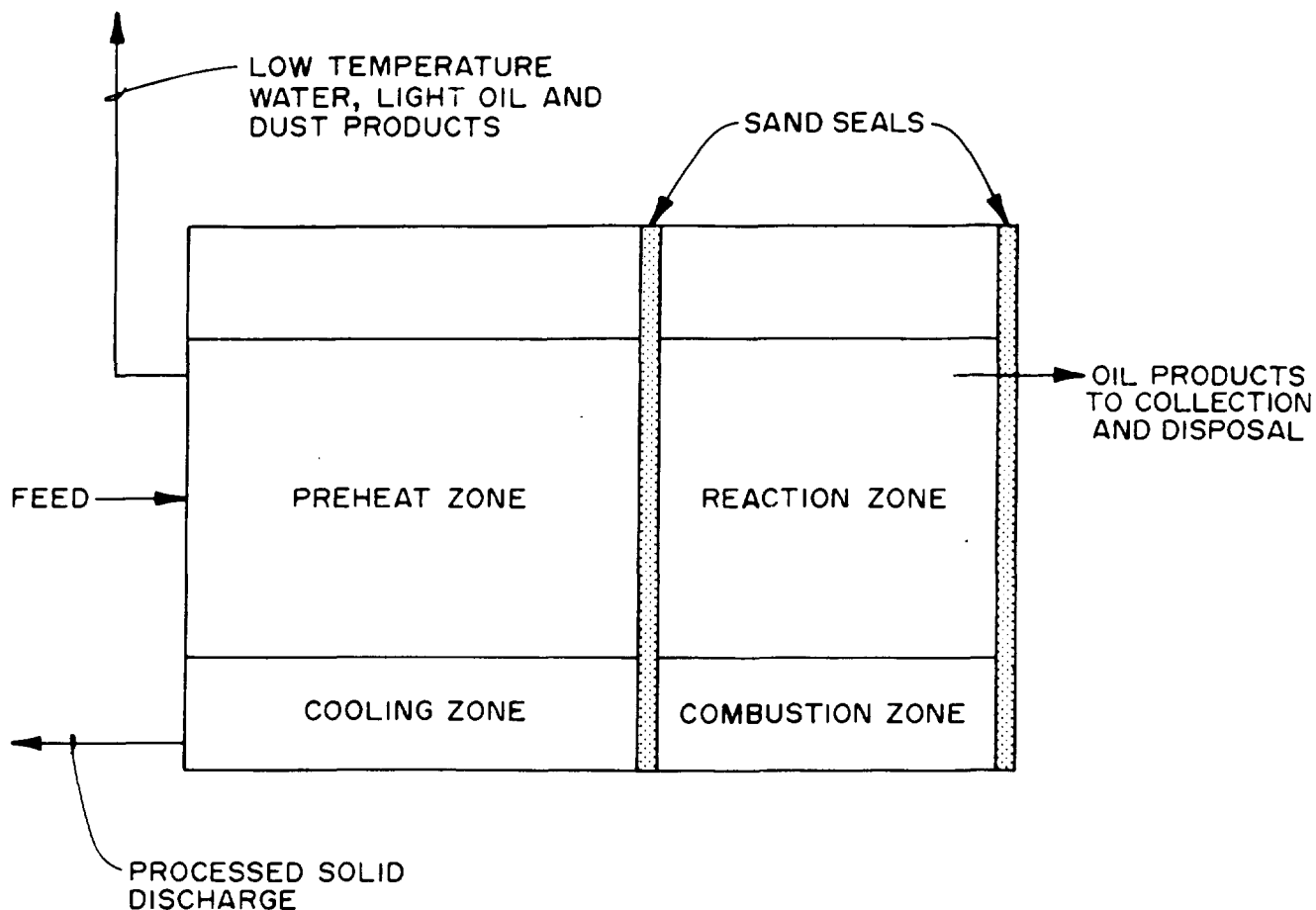
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 HLM

M.B.H.
 1-5-88

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 DATE

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SCHEMATIC DIAGRAM OF TACIUK PROCESS

PREPARED FOR

MARTIN, CRAIG, CHESTER &
 SONNENSCHNEIN
 CHICAGO, ILLINOIS

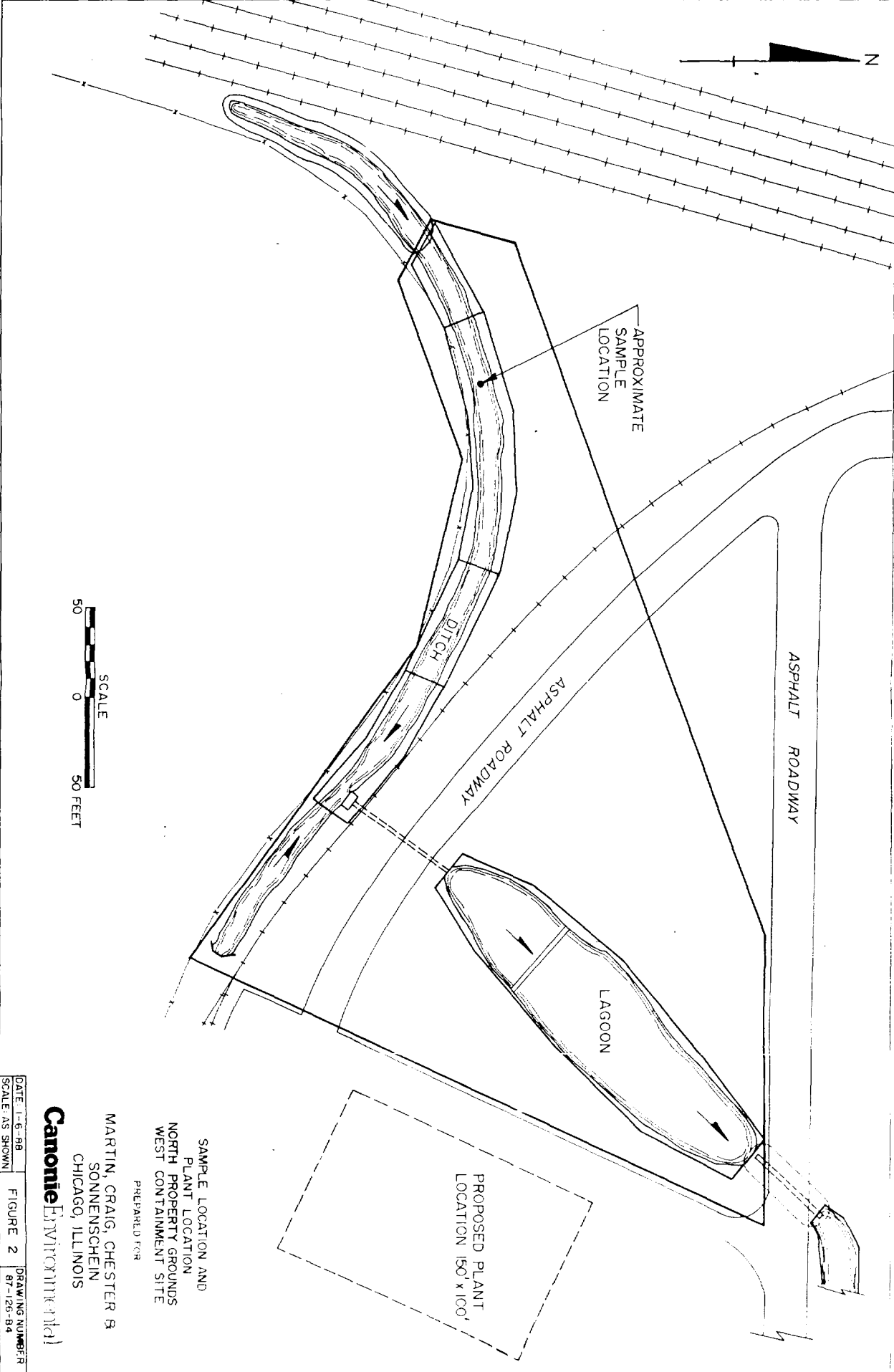
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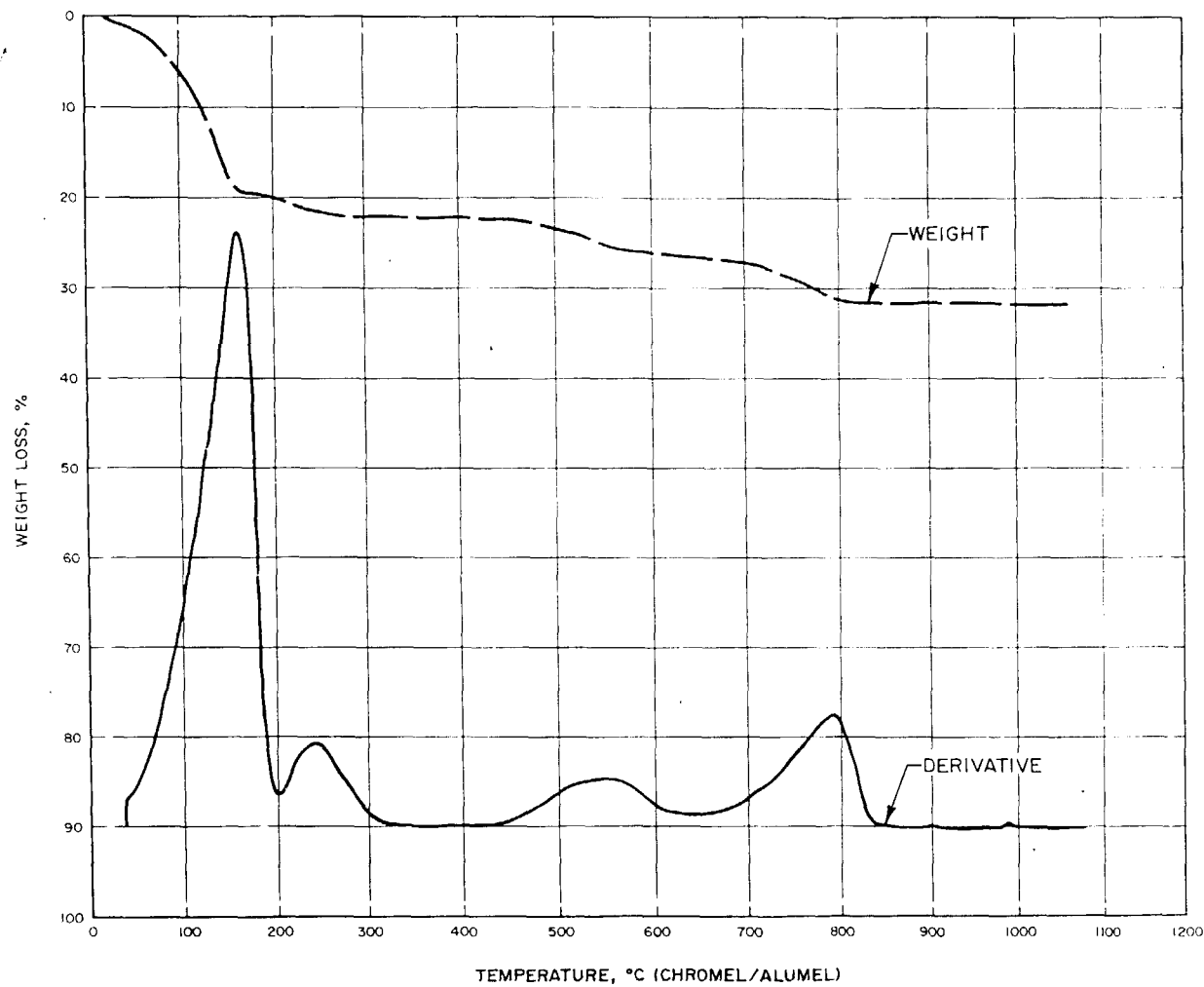
FIGURE 1

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SAMPLE LOCATION AND
PLANT LOCATION
NORTH PROPERTY GROUNDS
WEST CONTAINMENT SITE
PREPARED FOR
MARTIN, CRAIG, CHESTER &
SONNENSCHEN
CHICAGO, ILLINOIS
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SCALE AS SHOWN
FIGURE 2
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87-126-B4



THERMAL GRAVIMETRIC ANALYSIS
(TGA) OF CRESCENT DITCH SAND

PREPARED FOR

MARTIN, CRAIG, CHESTER &
SONNENSCHNEIN
CHICAGO, ILLINOIS

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DATE: 1-5-88	FIGURE 3	DRAWING NUMBER 87-126-B7
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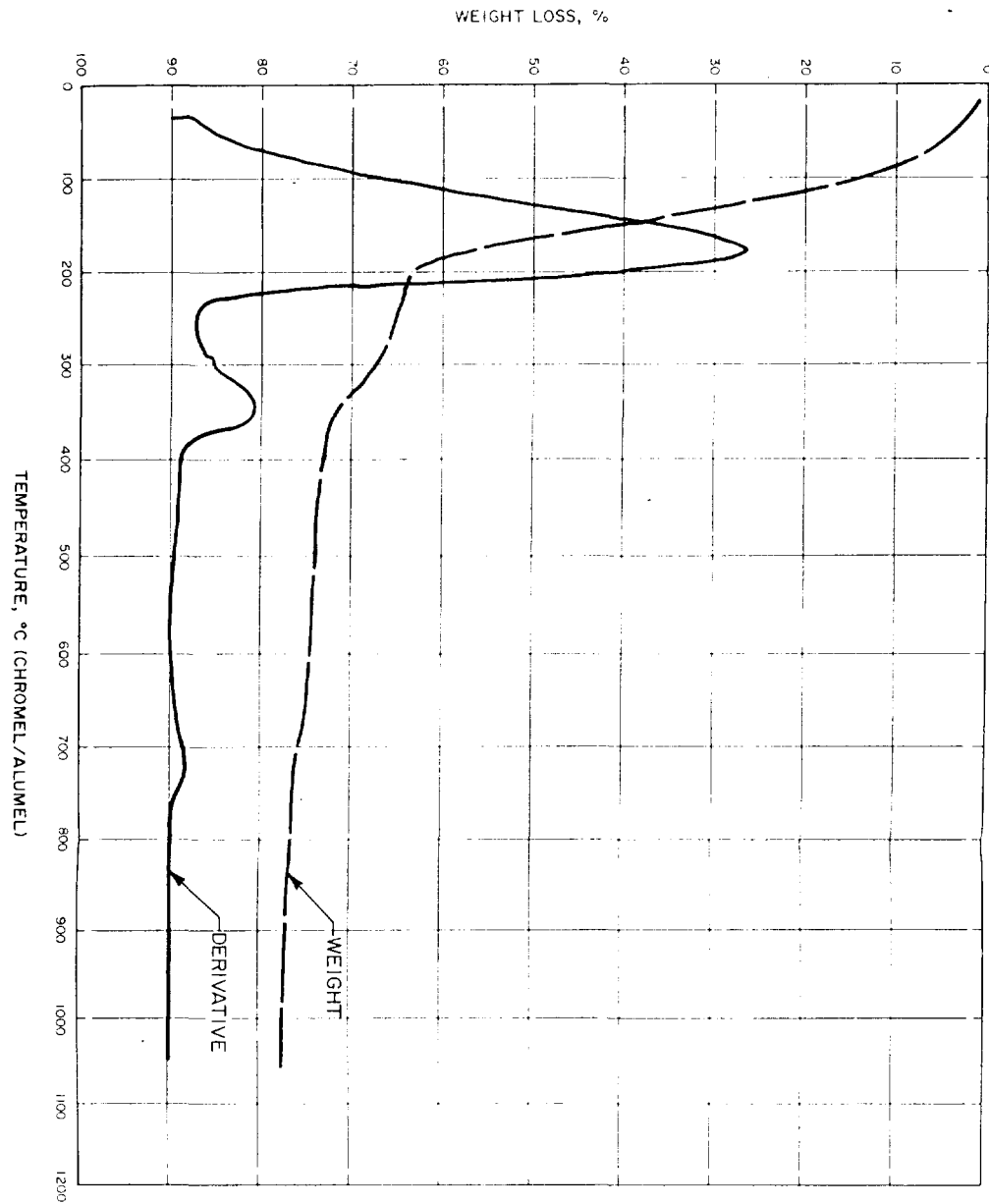
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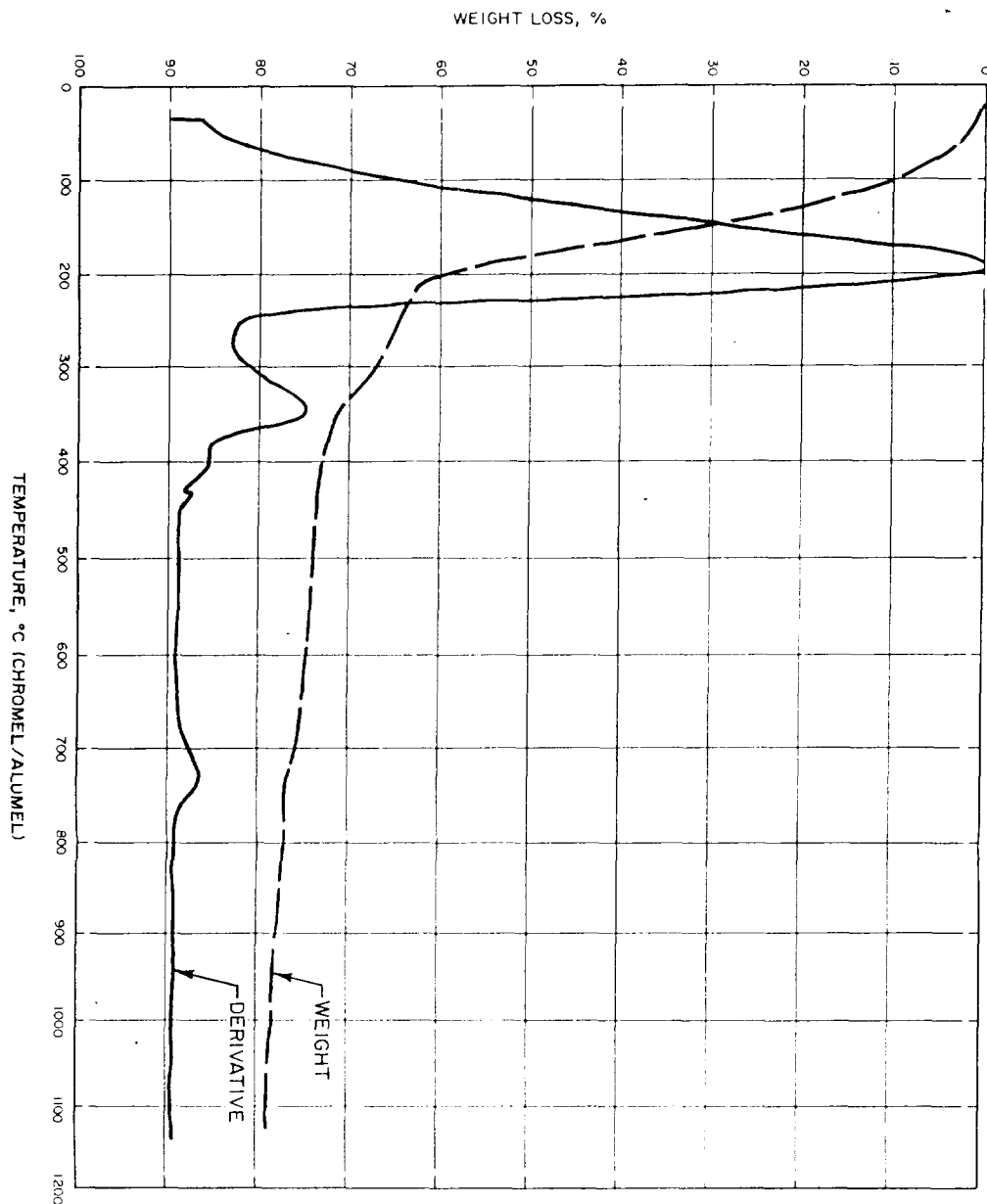


THERMAL GRAVIMETRIC ANALYSIS
(TGA) OF CRESCENT DITCH MUCK

PREPARED FOR

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DATE 1-5-88
SCALE AS SHOWN
FIGURE 4
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87-126-B5



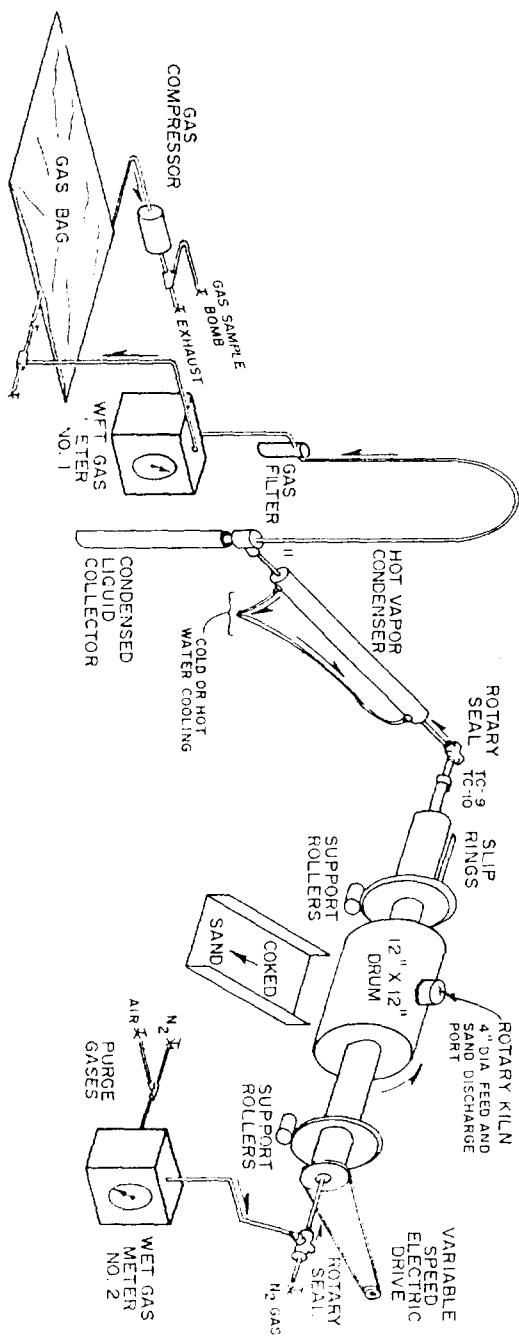
THERMAL GRAVIMETRIC ANALYSIS
OF CRESCENT DITCH MUCK (RERUN)

PREPARED FOR

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SONNENSCHNEIN
CHICAGO, ILLINOIS

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- DATA RECORDED
1. GTC's FROM ABOVE
 2. GAS FLOW RATE
 3. OIL LEVEL RISE RATE
 4. TEST DRUM PRESSURE
 5. CONDENSER DISCHARGE PRESSURE
 6. % O₂ IN OFF GAS (OPTIONAL)
 7. OTHERS AS REQUIRED

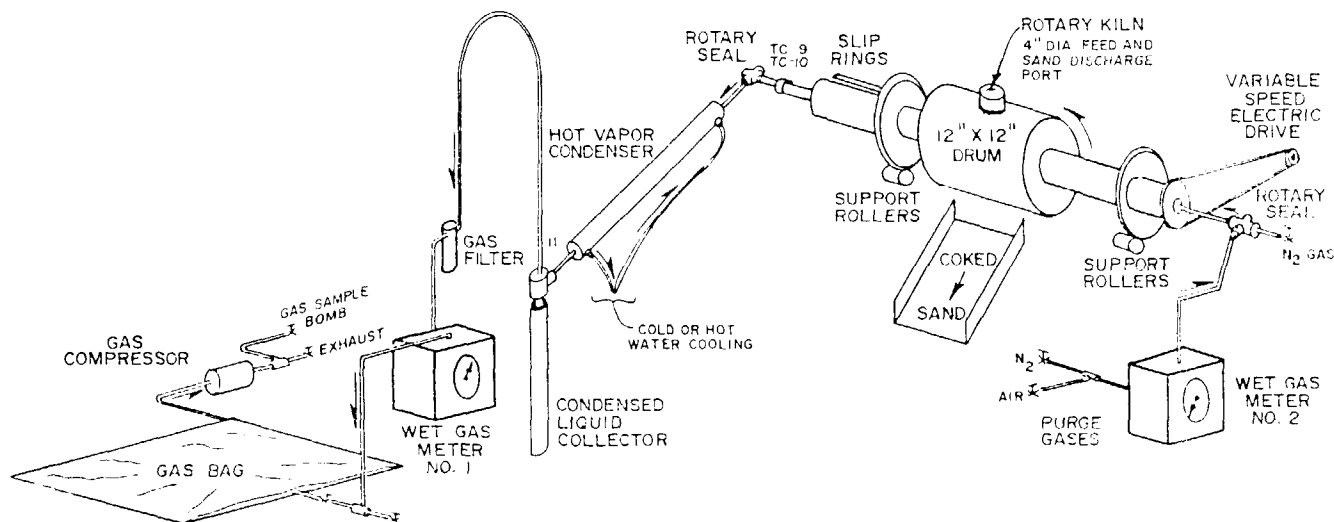


BENCH-SCALE THERMAL DESTRUCTION
TEST SET-UP

PREPARED FOR

MARTIN, CRAIG, CHESTER &
SONNENSCHNEIN
CHICAGO, ILLINOIS
Canon Environmental

DATE: 1-8-88
SCALE: N.T.S.
FIGURE 6
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DATA RECORDED

1. GTC's FROM ABOVE
2. GAS FLOW RATE
3. OIL LEVEL RISE RATE
4. TEST DRUM PRESSURE
5. CONDENSER DISCHARGE PRESSURE
6. % O₂ IN OFF GAS (OPTIONAL)
7. OTHERS AS REQUIRED

BENCH-SCALE THERMAL DESTRUCTION
TEST SET-UP

PREPARED FOR

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SONNENSCHNEIN
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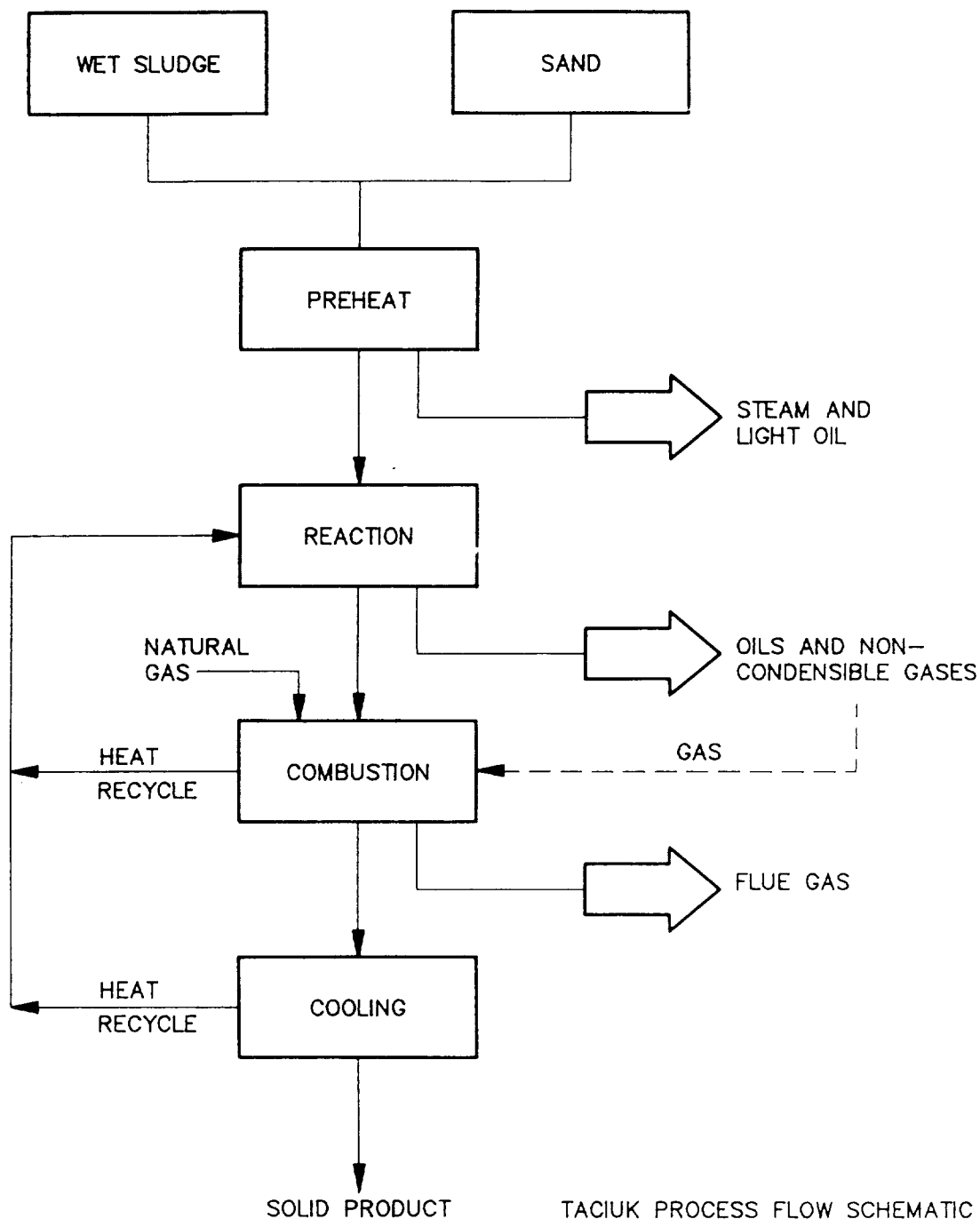
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SCALE: N.T.S.

FIGURE 6

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TACIUK PROCESS FLOW SCHEMATIC
OMC WASTES

PREPARED FOR

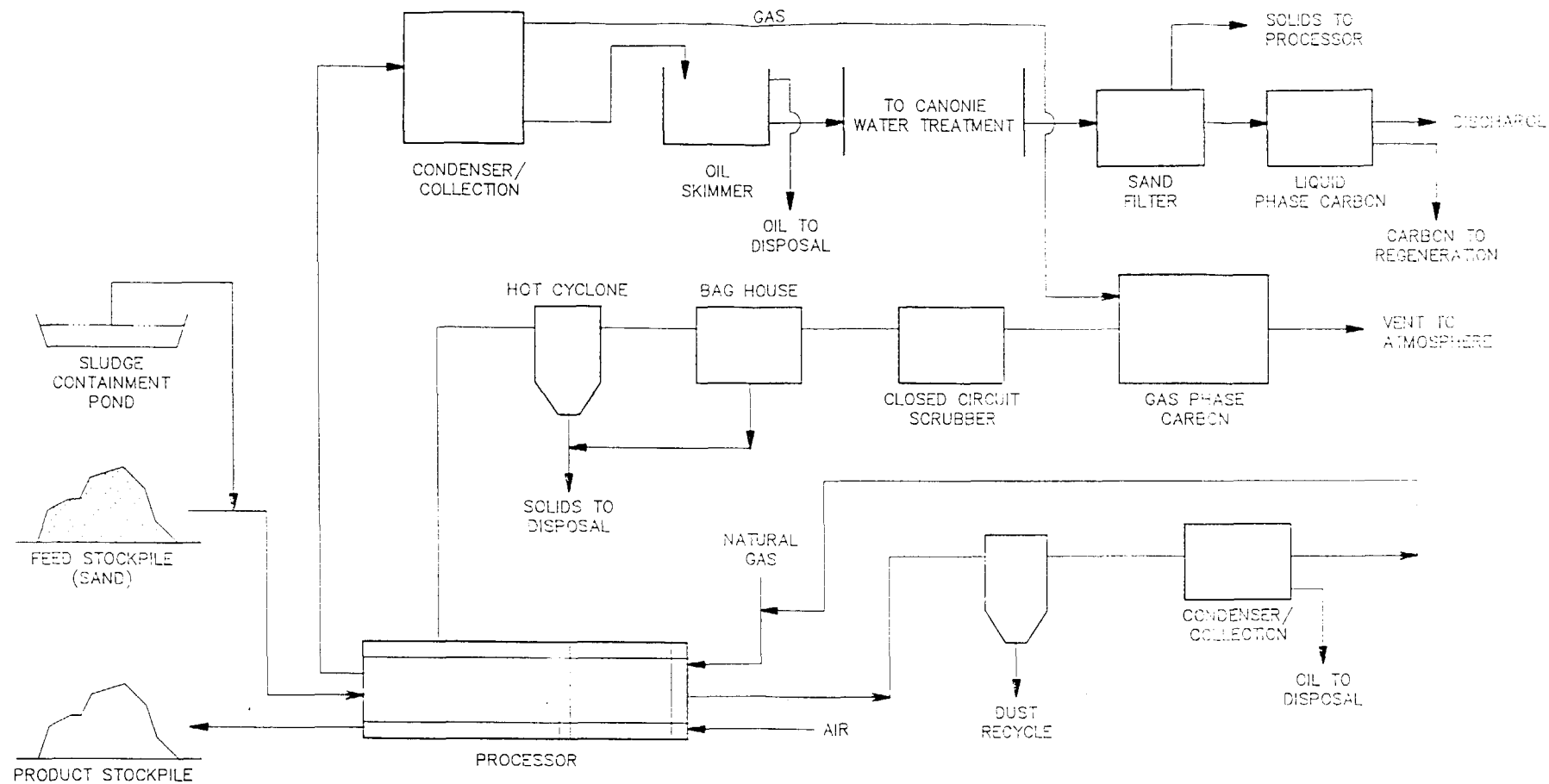
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FIGURE 7

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PRELIMINARY TACIUK PROCESS
FLOW DIAGRAM

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SONNENSCHEN
CHICAGO, ILLINOIS

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SCALE: NTS

FIGURE 8

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APPENDIX A
TECHNICAL REVIEW OF THE TACIUK THERMAL PROCESSOR

TABLE A-1

SUMMARY OF PILOT PLANT TEST SCHEDULE

1978, 1979, and 1980 (Phase A)

Reduced Crude	41 Runs
Oil Sand	63 Runs
Heat Exchange	17 Runs
Coke Combustion	15 Runs
Misc. Mechanical	42 Runs

Total Runs	178
------------	-----

1981 (Phase B)

Reduced Crude	16 Runs
Utah Oil Sands	3 Runs
Misc. Oil Sand	20 Runs
Misc. Other	21 Runs

Total Runs	60
------------	----

Extended Runs (Phase B)

Extended Run 1 (1981)	46 Hours
Extended Run 2 (1981)	75 Hours
Extended Run 3 (1981)	49 Hours
Extended Run 1 (1982)	82 Hours
Extended Run 1 (1982)	106 Hours
Extended Run 1 (1982)	73 Hours
Extended Run 1 (1982)	106 Hours
Extended Run 1 (1982)	27 Hours
Extended Run 1 (1982)	57 Hours

Total Hours	621
-------------	-----

1983 Testing (Phase 1)

Special Testwork (Phase 1)	
Oil Sand (Pilot Plant)	205 Hours
Tailings Sand	280 Hours

1984 through 1987 Testing

Australian Oil Shales	320 Hours
Refinery Waste Materials	30 Hours

Total Hours	1,210 Hours
-------------	-------------

TABLE A-2

SUMMARY OF FEED STOCK
TESTED BY UMATAC

<u>Feed Material</u>	<u>Batch Unit</u>	<u>Pilot Plant</u>
1. Low Grade Oil Sands	*	*
2. Average Grade Oil Sands	*	*
3. High Grade Oil Sands	*	*
4. Variable Grade Oil Sands	*	*
5. Suncor - High Fines Oils Sands	*	*
6. PETROCAN - High Fines Oil Sands	*	*
7. U.S. Low Grade Sand/Shales	*	*
8. Utah Oil Sands	*	*
9. Malagasy Consolidated Oil Sands	*	*
10. U.S. Low Grade Oil Shales	*	*
11. U.S. High Grade Oil Shales	*	Possible
12. Australian Oil Shales	*	1987
13. Australian Oil Shales	Large Batch	Schedule
14. Syncrude Coke	*	*
15. Lloydminster Heavy Oil - Husky	*	*
16. Cessford Crude Bottoms	*	*
17. Mobil Oil - Heavy Oil Cracker	*	Possible
18. Texaco Refinery Cleanup Wastes	*	*
19. McColl - L.A. Alkylation Wastes	*	Environ Possible
20. Heavy Oil Wastes (Lloyd Area)	*	Environ. Possible
21. Coal Tar Residues and Emulsions	*	
22. Rubber Tires	*	
23. Plastics	*	
24. API Separator - Bottoms Emulsions, etc. (for U.S. API Institutes)	*	Environ. Possible
25. Insitu Bitumen - Athabasca Bitumen	*	
26. U.S. Heavy Oil Wastes	*	
27. Brazilian Oil Shales	*	
28. New Zealand Peat Moss	*	
29. Israeli Oil Shales	*	
30. New Brunswick Oil Shales	*	

TABLE A-3

TONNAGE PROCESSED IN THE PILOT PLANT
PLUS 1,600 TONS OF AUSTRALIAN OIL SHALES
AND 100 TONS OF REFINERY WASTES

Feed Materials Processed in the Pilot Plant

3000 Tons	11-12% Syncrude Oil Sands
2500 Tons	11-13% Suncor Oil Sands
1200 Tons	9% Syncrude Oil Sands
300 Tons	14% Syncrude/Suncor Oil Sands
500 Tons	6-7% Suncor Oil Sands
600 Tons	6-8% Syncrude Oil Sands
600 Tons	8-10% Suncor Oil Sands
90 Tons	8% Utah Oil Sands
1000 Tons	7-9% Suncor Oil Sands
2000 Tons	11-13% Suncor Oil Sands
600 Tons	4-8% Malagasy Oil Sands
1000 Barrels	Gulf Reduced Crude
150 Barrels	Lloydminster Crude
1600 Tons	Australian Oil Shale
100 Tons	Texaco Refinery Waste

APPENDIX A

TECHNICAL REVIEW OF THE TACIUk THERMAL PROCESSOR

The Taciuk Processor has been developed over a period of seven years for the recovery of oil from Athabasca oil sands. Engineering studies have been completed by Associated-Pullman Kellog and Partec Lavelin, Inc., to compare the economics of the technology with the Clark Hot Water Process, which is now being used commercially to produce about 160,000 barrels per day of oil from Athabasca oil sands. Part of the development work was sponsored by Gulf Canada Resources, Inc., and Canstar Oil Sands Ltd. (a division of Petro-Canada). A summary of the development history of the technology is presented in Tables A-1 through A-3.

Technical Problems and Solutions

During the development program, several technical problems occurred which necessitated changes in the equipment and process design in order to meet the project goals. A review of how these problems were solved is useful in establishing the development level of the Taciuk Thermal Process and its ability to process the McColl and other refinery wastes.

Phase A

The purpose of Phase A was to determine the operating characteristics and parameters in each of the process zones, and the general operability of the equipment. The Phase A program lasted 3 years and cost \$2.4 million.

The early runs dealt with problems in the flow of solid materials through the kiln, and in measuring heat exchange in the preheat zone. The first oil runs were made by injecting a topped crude oil into the reaction zone while recirculating a charge of sand. Development work focused on the

performance of the reaction zone, limiting seal leakage between the zones, combustion of the resulting coke on the sand, and improvements to the oil vapor condensing system. Based on this data, the throughput capacity of the processor and the design of the oil vapor condensing system were established.

Operation on oil sand introduced the new problem of dealing with steam generated from water in the oil sand, requiring changes in the design of the vapor handling system. An apparent absence of light materials in the product oil was noticed. This was overcome by installing an overhead gas refrigeration system to collect the light ends being lost to the flare.

Combustion of coke was inadequate to provide the heat requirements of the process. A small reactor was developed and tested in cooperation with the Canadian Combustion Research Laboratory. Based on the results of these tests, the kiln was modified to improve the design of the combustion zone.

The effect of increasing the feed rate to the processor was found to be excessive tailings temperature, combustible materials in the combustion zone flue gas, and an inability to maintain reaction temperatures with auxiliary burner firing. These problems were partly overcome by improving the design of the preheat and combustion zones.

Phase B

The purpose of Phase B was the generation and evaluation of performance data which was to be obtained during continuous operation of the processor. The Phase B program lasted 2.5 years and cost \$3.25 million.

During Phase B, the processor was rebuilt to incorporate the design changes needed to meet the development objectives. A preheat steaming zone was added to take care of connate water. Modifications were made to the design of the reaction and combustion zones, and to the seals around the reaction zone. More positive control of sand flow and bed levels were added, and

structural changes were made to refractory insulation and mechanical support. Changes were made to the gas and vapor collection system, including expansion of the condensing capability, recycle of tower bottoms containing dust carryover from the reactor, rebuilding of the hot vapor cyclone system, and rebuilding of the flue gas scrubber for removal of sulfur dioxide.

As a result of these modifications, the liquid yields and material balance closures were significantly improved over those measure in Phase A. Oil analyses carried out by Gulf Canada's Research Laboratory confirmed the oil quality was similar to that obtained from commercial state of the art fluid coking processing.

The continuous runs in Phase B successfully demonstrated the key technical factors in the design of the processor including:

- a) Steady state product quality and yield
- b) Ability to handle feed composition changes
- c) Ability to shut down, restart, and reach operating conditions in the reactor over a short period of time.

The data collected during these runs were of sufficient quality to prepare computer models of the key process steps in the various zones of the reactor. Additional heat exchange combustion and solid transport data for the models were collected from special tests in small batch reactors followed by verification in the pilot unit.

Phase 1

The purpose of Phase 1 was to compare the economics of the Taciuk Thermal Process with technology currently being used to commercially produce oil from Athabasca oil sands, and to complete the design of a commercial

demonstration unit from the results of Phase A and B testwork, and from additional special tests. The Phase 1 demonstration plant design and feasibility program took about 1.75 years at a cost of \$4.5 million.

The Phase 1 activities resulted in the completion of design data books for the processor. This design information was used by the engineering contractor (Partec Lavalin) for a feasibility comparison of the Taciuk technology with established commercial technology.

Additional pilot plant runs were made to obtain data on improvements in heat exchange design, seal improvements, prevention of coke build-up, and improved gas scrubbing efficiency. Horizontal sand trajectories were modeled to limit the amount of dust transport with the product off-gas, and mechanical improvements were made to the kiln drive system.

APPENDIX B
RESULTS OF BENCH SCALE TESTWORK

APPENDIX B

RESULTS OF BENCH SCALE TESTWORK

Four tests were conducted on muck and sludge samples from the Crescent Ditch site. The test identification is:

T1011	Crescent Ditch muck added to a hot silica sand bed
T1012	Crescent Ditch sand heated from room temperature
T1013, T1014	Crescent Ditch muck premixed with sand and heated from room temperature

In Test 1011, the Crescent Ditch muck was added to the hot batch test unit in plastic bags. This resulted in higher levels of fines carryover. Subsequent tests (T1013 and T1014) were run on a muck/sand premix in the ratio of 2.2 parts sand to one part muck.

Test Conditions

Raw Data sheets identifying test conditions are attached. The conditions were:

Test 1011	Preheat sand bed to 300°F
	Add charge and increase to 500°F
	Remove volatilized liquids (Res. A)
	Increase temperature to 1,110°F
	Remove volatilized liquids (Res. B)
	Test time 117 minutes

Test 1012	No preheat Increase temperature to 375°F Remove volatilized liquids Increase temperature to 550°F - No further liquid production Increase temperature to 1,100°F Additional water removed at 650°F Oil removed at 785°F Test time 118 minutes
Test 1013	No preheat Test conditions similar to Test 1011 Longer retention time 171 minutes
Test 1014	No preheat Test conditions similar to Test 1011 Shorter retention time 90 minutes

Attachment B-1 presents the raw data from the test runs.

Test Results

The liquid products and solid products from each run were analyzed for PCB. The char product for each test was burned in air and the burned products were assayed for PCB. The char and ash products from Test 1011 were assayed for 2,3,7,8 dioxin. Attachment B-2 presents the results of these analyses. Attachment B-3 presents the results of the QA/QC check assays. Attachment B-4 presents the results of 2,3,7,8 Dioxin analysis on the char and burned solids from T1011.

Preliminary comparisons have been made between the PCB composition in the feed and product materials. The analysis work was performed by Chemex in Calgary, Alberta. Comparisons are attached and indicate that the PCB will not break down during the process. Both the feed and product species are

Aroclor 1242. Additional more detailed work, however, to substantiate this observation may be required. Attachment B-5 presents the PCB composition comparison. Aroclor 1242 has also been independently verified in the feed and products by Canonie's laboratory in Stockton, California.

Conclusion

The following conclusions have been reached:

- 1) All the products produced by the process except the solids discharge contain PCBs.
- 2) The PCBs occur primarily in the oil products. PCBs in the water products are likely to be contained in entrained solids and oils. It is expected that these components will be removed by the filtration liquid phase carbon water treatment process.
- 3) The majority of PCBs report to the high temperature oil products. The PCBs do not appear to be decomposed during processing, but this conclusion needs to be justified by additional laboratory work.
- 4) The charred material does not contain detectable levels of PCB. Consequently, concentrations of oxidation products such as dioxin and/or dibenzofurans are not expected in the flue gas stream. Neither the char or the combusted material contain dioxins.

Material Balances

Material Accountability for gases, liquids, and solids produced in the process is generally with ± 5 percent. Accountability for PCBs was about 36 percent for the muck and 45 percent for the solids (Tables B-1 and B-2). The lack of PCB accountability cannot be quantified in these preliminary test runs. Re-runs on feed assays indicate a 4/1 range on the muck sample.

In addition, dilutions of 20,000 to 30,000 were required since the analytical techniques used are for trace PCB concentrations. These procedures can lead to extreme errors.

Laboratory work is continuing to resolve this problem. At the present time, it is reasonable to assume that the error can be resolved and does not impact the predicted performance of the Processor.

ATTACHMENT B-1
RAW DATA SHEETS

FIELD DATA FOR BATCH RETORT UNIT

note: Temperatures are °F, weights in grams, pressure in mm Hg
 RUN PURPOSE - SPECIAL CONDITIONS - NOTES -
 gas volumes are meter readings & not corrected to STP or NTP actual
 → 500°F 0.20 C + gas

At ≈ 300°F add charge increase to 500°F Bed

Hold. Remove Liquid Ramp to ≈ 1100°F

until gas subsides let - 87

8718-02 - MAKE 8

Sample # 8718-01 - sandy mat 1, 8718-02 - sludge

RUN NO - 1011

DATE - 871213

FEED TYPE - 8718-02

RUN LENGTH - 117 min

UNIT SPEED - 3.5 rpm

TEMPERATURE °F

RECYCLE DETAILS			FEED DETAILS			TEMPERATURE °F	
						INITIAL	FINAL
TYPE - sil 4	(7)		TYPE - 8718-02	(5)		FEED - 50	(35)
ANALYSIS - %LOI -	(34)		ANALYSIS - %OIL -	(35)		RECYCLE - 50	(14)
						SHELL - 50	(11) 1163
						BED - 50	(11) 1116
						MIN. BED -	(13)
						AMBIENT - 61	

SPECIFIC GAS PURGE DETAILS -		AMB. TEMP - 61 (30)	GAS PRODUCED - (C.F.)	1.05
		PRESS "Hg - 681 (37)	TOTAL H ₂ AMB. - (C.F.)	1.0 (3)
			FINAL GAS - (C.F.)	2.05 (1)

	RESERVOIR LIQUID	COND. TUBE BLOW DOWN	FILTER	TUBE WIPINGS	GAS BAG	LIQUID WATER %
GROSS-GR	1352.5	841.7	6%	1944.1	10.1	
TARE-GR	736.5	736.5	6%	1944.1	6.0	
NET-GR	617.0	155.2	3.0	0	4.1	

	SOLIDS IN LIQUID	OTHER??	RETORT SCRAPINGS	HOT VAPOR LINE FINES	SPENT SOLIDS (TAILINGS)	LIQUID SOLIDS %
LOT-%	(32)			(40)	1.46	(33)
OTHER -						
GROSS-GR				2366.1	2675.4	
TARE-GR				2293.8	424.9	
NET-GR				72.3	2250.5	

NOTE PROBLEMS WITH RUN -

RUN NET LIQUID	779.3
RUN NET SOLIDS	2322.5
RUN GAS - C.F. X: 83	34.65
SUM OF PRODUCTS	3136.8
% PRODUCTS FEED + REC.	97.7 %
CLEANED OIL	
API -	(36)
ROR -	(3)
OIL % -	(4)
SOLIDS % -	(5)

12 000000 00 000000 0

1200

12 000000

12 000000 MANUAL INJECTION @ 15:39 DEC 13, 1987

12 000000 00 000000 0

1200

1

AREA TYPE ORL AMOUNT NAME

1.47	24992.50	88	24	0.520	61# C6+	Hexanes & heavier 8 SO ₂ if present
7.91	3306.53	88	17	15.872	38# H2	Hydrogen
3.33	27044.10	WV	1	0.814	39# C3	Propane
3.91	44727.00	WV	2	1.540	40# C3=	Propane
12.30	7559.47	++	3	0.220	41# I-C4	Butenes
13.96	5037.05	8V	4	0.144	43# N-C4	
15.04	6608.12	8V	5	0.204	44# I-C4=	Butenes
16.71	6608.12	VP	27	1.097	44# I-C4=	
16.71	37087.70	88	6	0.131	45# T-2-C4=	
19.09	4441.55	8V	7	9.559E-02	46# C-2-C4=	Pentane
21.32	3274.93	WV	8	2.588E-02	47# I-C5	Butene Butadiene
21.32	974.98	88	25	0.173	46# I-3-C4=	Butene Butadiene
21.32	5575.89	88	9	5.886E-02	48# N-C5	Pentane
23.14	2335.50	88	10	0.111	50# I-C5=	Pentenes
23.95	4259.22	88	19	4.929E-02	51# T-2-C5=	
23.95	1879.53	8V	20	4.993E-02	49# I-1-C5=	
23.95	1869.22	WV	21	1.329E-02	52# C-2-C5=	
23.95	597.55	++	22	7.742E-02	53# I-2-C5=	Carbon Dioxide
23.95	2957.76	++	22	24.135	58# C02	
23.95	551975.00	WV	14	1.494	59# C02=	Ethylene
23.95	37263.70	WV	15	1.662	60# C2	Ethane
23.95	42396.60	WV	16	0.912	54# C2	Oxygen
23.95	15966.90	WV	10	43.569	55# N2	Nitrogen
23.95	833353.00	+	11	4.780	56# C1	Methane
23.95	91257.10	WV	12	2.166	57# C0	Carbon Monoxide
23.95	44739.30	WV	13			

12 000000 00 000000 0

RUN PURPOSE - SPECIAL CONDITIONS - NOTES -

Gas Reading at removal of reservoir A was 0.24 wt
 Ramp $\rightarrow 353^{\circ}\text{F}$ Bad $375 \rightarrow 400^{\circ}\text{F}$ shell Remove water
 Ramp $\rightarrow 550^{\circ}\text{F}$ Bad @ 600° shell - No more liquid -
 Water started @ $\approx 650^{\circ}\text{F}$ Bad 950°F shell
 Oil " @ $\approx 785^{\circ}\text{F}$ Bad 872°F shell

DATE - 5/7/2/4

FREQ - 8715-C1

Run Length - 115

UNIT SPEED - 35

TEMPERATURE OF

RECYCLE DETAILS			FEED DETAILS		
TYPE -		(7)	TYPE - 8718-01		(5)
ANALYSIS - %LOI -		(94)	ANALYSIS - %OIL -		(35)
	COLD	HOT		COLD	HOT
GROSS-GR			GROSS-GR	4380.4	
TARE GR			TARE GR	668.7	
NET-GR	(6)	(2)	NET GR	3711.7 (4)	(4)

	INITIAL	FINAL
FEED -	60	(85)
RECYCLE -	60	(14)
SHELL -	77	(41)
BED -	60	1089
MIN. BED -		(13)
AMBIENT -		

SPECIFIC GAS PURGE DETAILS -

AMB. TEMP - 59

Press "Ng-670-7" GT

GAS PRODUCED-CF)	1.33
------------------	------

TOTAL H₂ ADDED (C.F.) 2.17 (5)

Final Gas - C.F. 3.52 (1)

	RESERVOIR LIQUID		COND. TUBE BLOW DOWN	FILTER	TUBE WIPINGS	GAS BAG	LIQUID WATER %	
GROSS-GR	1259.9	427.0	633.2	1945.3	3.2		LIQUID SOLIDS %	
TARE-GR	735.9	730.9	632.2	1943.9	3.0			
NET-GR	524.0	96.2	1.0	1.4	0.2		RUN NET LIQUID	526.5
							RUN NET SOLIDS	3094.4
							RUN GAS- C.F.X:83	439
							SUM OF PRODUCTS	3665.1
							Σ PRODUCTS FEED + REC.	48.7
							CLEANED OIL	
							API -	
							RGR -	
							OIL S -	
							SOLIDS S -	
NOTE PROBLEMS WITH RUN-								

FIELD DATA FOR BATCH RETORT UNIT

RUN PURPOSE - SPECIAL CONDITIONS - NOTES -

Feed 8718-02 ^{pre-}mixed with Silica

(proportions 2547.9g feed with 5662.5g sand)

Switch reservoirs at 0.23 left of gas

RUN NO - 1013

DATE - 871214

FEED TYPE - 8718-02

RUN LENGTH - 171

UNIT SPEED - 3.5

TEMPERATURE OF

RECYCLE DETAILS

FEED DETAILS

TYPE -
ANALYSIS - %LOI -

(7)

(34)

TYPE - 8718-02 & sand
ANALYSIS - %OIL -

(5)

(35)

GROSS-GR

COLD

HOT

GROSS-GR

COLD

HOT

TARE GR

TARE GR

NET-GR

(6)

(2)

NET GR

3490.1

(4)

(4)

INITIAL

FINAL

FEED - 60

(35)

RECYCLE -

(14)

SHELL - 267

(4)

1133

BED - 60

(13)

1088

MIN. BED -

AMBIENT -

SPECIFIC GAS PURGE DETAILS -

AMB. TEMP - 60

PRESS. HG - 670.7

GAS PRODUCED - (CF) 0.71

TOTAL H₂ AMB. - (CF) 1.0

FINAL GAS - (CF) 1.71

	RESERVOIR LIQUID		COND. TUBE Blowdown		FILTER	TUBE WIPINGS	GAS BAG	LIQUID WATER %
GROSS-GR	#1 1265.4	#2 771.9	#3 806.5	CT Blowdown	1949.4	4.0		LIQUID SOLIDS %
TARE-GR	735.7	731.5	732.1		1949.4	3.0		
NET-GR	529.7	40.4	69.4	0	0	1.0		

	SOLIDS IN LIQUID	OTHER??	RETORT SCRAPINGS	HOT VAPOR LINE FINES	SPENT SOLIDS (TAILINGS)	RUN NET LIQUID
LOT-%	(32)			(87)	(33)	639.5
OTHER-						
GROSS-GR				2302.9	3208.2	RUN NET SOLIDS 2795.6
TARE-GR				2290.0	425.5	RUN GAS - C.F.X:83 23.43
NET-GR				12.9	2782.7	SUM OF PRODUCTS 3458.5
						± PRODUCTS FEED + REC. 991 %
						CLEANED OIL
						API -
						RGR -
						OIL S -
						SOLIDS S -

NOTE PROBLEMS WITH RUN -

=====

=====

=====

===== INJECTION @ 15:35 DEC 14, 1987

=====

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ST

TYPE CAL AMOUNT NAME

1	0030.73	03	24	0.232	61+ 06+
2	405.67	03	17	3.014	33+ 12
3	10613.50	V3	1	0.355	39+ 03
4	10071.50	03	2	0.386	43+ 03=
5	3669.62	++	3	0.113	41+ 1-04
6	1742.16	0V	4	5.556E-02	43+ N-04
7	3442.13	03	27	0.793	41+ 1-04=
8	1131.97	03	6	3.375E-02	45+ 1-2-04=
9	324.73	03	7	3.338E-02	46+ 0-2-04=
10	534.29	0V	3	1.576E-02	47+ 1-03
11	2126.56	03	25	1.537E-02	46+ 13-04=
12	733.37	03	9	2.268E-02	48+ N-03
13	574.95	03	13	1.275E-02	50+ 1-05=
14	882.22	0V	19	2.351E-02	51+ 1-2-05=
15	407.00	V3	20	1.198E-02	49+ 1-1-05=
16	137.97	++	21	3.726E-03	52+ 0-2-05=
17	35500.00	0V	14	19.212	58+ 002
18	5431.00	VV	15	0.242	59+ 02=
19	11422.10	V3	16	0.493	60+ 02
20	13222.70	VV	10	1.232	51+ 02
21	1156570.00	VV	11	70.196	55+ 02
22	32914.20	VV	12	2.350	56+ 01
23	34720.90	VV	13	1.350	57+ 00

=====

MANUAL INJECTION @ 08:39 DEC 15, 1987

SET POINT FOR DEVICE# 6

REPORT

MANUAL INJECTION @ 08:39 DEC 15, 1987

STANDARD 97.100

TIME	TYPE	CTL	AMOUNT	NAME
11:47.40	SS	24	0.457	51* C6+
11:48.47	SS	17	4.092	38* M2
11:49.30	WS	1	0.430	39* C3
11:49.50	SS	2	0.761	40* C3=
11:50.57	++	3	5.917E-03	41* I-C4
11:54.30	SV	4	7.930E-02	43* N-C4
11:56.04	SV	5	0.148	44* I-C4=
12:00.20	VS	27	0.414	44* I-C4=
12:07.41	SS	6	8.235E-02	45* T-2-C4=
12:17.70	SV	7	6.319E-02	46* C-2-C4=
12:21.10	VS	8	1.367E-02	47* I-C5
12:29.84	SS	25	9.350E-02	45** 13-C4=
12:31.33	SS	9	3.019E-02	48* N-C5
12:37.11	SS	13	5.937E-02	50* I-C5=
12:47.41	SV	19	2.750E-02	51* T-2-C5=
12:50.37	VS	20	2.680E-02	49* I-1-C5=
12:58.89	++	21	5.73E-03	52* C-2-C5=
13:03.00	SV	14	9.904	53* C02
13:05.10	VS	15	0.859	59* C2=
13:15.60	VS	16	0.933	60* C2
13:25.10	SV	10	1.754	54* C2
13:37.00	VS	11	27.336	52* N2
13:41.10	VS	12	1.814	56* C1
13:50.40	VS	13	0.555	57* C0

ATTACHMENT B-2
CHEMICAL ANALYSES (CHEMEX)

CHEMEX

Labs Alberta (1984) Ltd.

ATTN: BOB RITCHEY

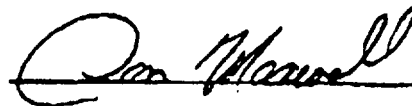
DEC. 18, 1987

UMATAC INDUSTRIAL PROCESS

UMAT010-1001-87-6682

SAMPLE	CONC OF PCB PPM	TYPE
1011 COMBUSTED MATERIAL	L0.1	
1012 COMBUSTED MATERIAL	L0.1	
1101 SAND	L0.1	
1012 SAND	L0.1	
8718-01 SLUDGE	26,437 (WT/WT)	1242
8718-02 SLUDGE	61,335 (WT/WT)	1242
8718-01 WATER	563 (WT/VOL)	1242
8718-01-B OIL	68,861 (WT/VOL)	1242
WATER	114 (WT/VOL)	1242
SLUDGE	10,223 (WT/WT)	1242
8718-02-A OIL	235,308 (WT/VOL)	1242
WATER	16 (WT/VOL)	1242
1011A OIL	50,877 (WT/VOL)	1242
WATER	70 (WT/VOL)	1242
SOLIDS	5492 (WT/WT)	1242
1012B WATER	12 (WT/VOL)	1242
OIL	959,170 (WT/VOL)	1242

NOTE: "L" DENOTES "LESS THAN"



DON MAXWELL

CALGARY	2021 - 41 Avenue N.E., Calgary, Canada T2E 8P2 Tel.: (403) 291-3077
EDMONTON	9331 - 48 Street, Edmonton, Canada T6B 2R4 Tel.: (403) 466-9877
GRANDE PRAIRIE	#106, 8502 - 112th Street, Grande Prairie, Canada T8V 5X4 Tel.: (403) 532-0227
HIGH LEVEL	10509 - 95 Street, High Level, Canada T0H 1Z0 Tel.: (403) 926-2448
ESTEVAN, SASK.	Apex Analytical Laboratories Ltd., 483 Devonian St., Estevan, Canada Tel: (306) 634-9112

CHEMEX

Labs Alberta (1984) Ltd.

UMAT010-1001-87-6691

UMATAC INDUSTRIAL PROCESSES

ATTENTION: R. RITCHEY

RESULTS FOR PCB ANALYSIS

<u>SAMPLE NUMBER</u>	<u>SAMPLE TYPE</u>	<u>PCB,s, ppm</u>	<u>AROCLOR</u>
8718-01	Sludge	28,963	1242
8718-02	Sludge	16,866	1242
1013-A	Water	790	1242
1013-A	Oil	313,692	1242
1013-B	Water	1 335	1242
1013-C	Oil	81,908	1242
1014	Oil	96,260	1242
1014	Water	169	1242


FOU PON

CALGARY 2021 - 41 Avenue N.E., Calgary, Canada T2E 8P2 Tel.: (403) 291-3077
EDMONTON 9331 - 48 Street, Edmonton, Canada T6B 2R4 Tel.: (403) 465-0677
GRANDE PRAIRIE #106, 8502 - 112th Street, Grande Prairie, Canada T8V 5X4 Tel.: (403) 532-0227
HIGH LEVEL 10508 - 95 Street, High Level, Canada T0H 1Z0 Tel.: (403) 926-2448
ESTEVAN, SASK. Apex Analytical Laboratories Ltd., 483 Devonian St., Estevan, Canada Tel: (306) 634-9112

CHEMEX Labs Alberta (1984) Ltd.

ANALYTICAL BULLETIN

QA/QC

Using **Chemex Labs** for your analytical needs gives you far more than numbers You receive reliable accurate results. Quality assurance/quality control is only one of the means **Chemex Labs** uses to provide them. This and other procedures **Chemex Labs** takes to ensure this quality are described below.

INTERNAL QUALITY CONTROL

As much as 20% of our analyses are actually quality control related. These include analysis of the following:

- spikes (addition of a known concentration)
- standards
- preservatives
- standard reference materials
- duplicates

EXTERNAL QUALITY CONTROL

Chemex Labs actively participates in and often organizes inter-laboratory comparison studies.

QUALITY ASSURANCE OFFICER

Chemex Labs employs a full-time Quality Assurance Officer who is responsible for monitoring the precision and accuracy of our analyses. Results and recommendations are submitted daily to the Manager of Analytical Services.

LABORATORY CERTIFICATION

Since 1983, the Environmental Protection Agency in the United States has certified **Chemex Labs**. Analytical acceptability is monitored through comprehensive inter-laboratory sample exchanges.

INTERNAL CHECKS AND BALANCES

Analytical results determined by Chemex Labs are subjected to a rigorous set of computerized chemical checks and balances before being released to the client.

PERSONNEL

The generation of accurate, precise and reproducible analytical results requires years, not months of training and experience. Chemex Labs management and supervisory personnel each have in excess of fifteen years of directly related experience. Technical personnel have an average of six years of experience.

WHAT ARE THE BENEFITS OF THESE FEATURES TO YOU?

By carrying out these Quality Assurance/Quality Control related procedures, Chemex Labs can confidently offer you the highest standard of analytical services. This means you can have confidence in your analytical results and the interpretations made from them.

If you already use Chemex Labs, you have seen the proof and are benefitting by it. If you do not use Chemex Labs, yet want the best value for your analytical budget, please contact us.

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ATTACHMENT B-3
CHECK CHEMICAL ANALYSIS (CANONIE)

12-29-1987
87-903-3267
Page 1

Table 1
Codes of Samples Received
From OMC
Project: 87-903

<u>Sampler ID</u>	<u>Date Sampled</u>	<u>Date Received</u>	<u>Lab ID#</u>	<u>Sample Type</u>	<u>Container</u>
Analysis: PCB					
1011	—	12-19-87	722139	Soil	250ml Glass
1011 Burn T	—	12-19-87	722140	Soil	250ml Glass
1012	—	12-19-87	722141	Soil	250ml Glass
1012 Burn T	—	12-19-87	722142	Soil	250ml Glass
1013	—	12-19-87	722143	Soil	250ml Glass
1013 Burn T	—	12-19-87	722144	Soil	250ml Glass

Table 2
Results of PCB Analysis on Soil
Samples Received From OMC
Results in mg/kg

12-29-1987
87-903-3267
Page 2

Sampler ID:	1011	1011	1012	1012	1013
		Burn T		Burn T	
Lab ID#:	<u>722139</u>	<u>722140</u>	<u>722141</u>	<u>72142</u>	<u>722143</u>
<u>Analyte(s)</u>					
PCB's quantified as PCB 1242	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1
PCB's quantified as PCB 1254	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1
PCB's quantified as PCB 1260	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1

DMA DEG
Analyst Checked by

Note:

ND X denotes none detected to a level of X

#ND X denotes none detected to a level of X due to an interfering peak

Canonic Environmental

Table 2 (Cont.)
Results of PCB Analysis on Soil
Samples Received From OMC
Results in mg/kg

12-29-1987
87-903-3267
Page 3

Sampler ID:	1013
Lab ID#:	Burn T <u>722144</u>
<u>Analyte(s)</u>	
PCB's quantified as PCB 1242	ND 0.1
PCB's quantified as PCB 1254	ND 0.1
PCB's quantified as PCB 1260	ND 0.1

Dma DEG
Analyst Checked by

Note:

ND X denotes none detected to a level of X.

/ND X denotes none detected to a level of X due to an interfering peak.

CanonieEnvironmental

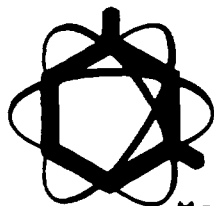
Reference Methods

PCB'S

	<u>Preparation</u>	<u>Analysis</u>
Water	<input type="checkbox"/> EPA 3510 <input type="checkbox"/> EPA 3520	<input type="checkbox"/> EPA 608.3 <input type="checkbox"/> EPA 625
Soil	<input type="checkbox"/> EPA 3540 <input checked="" type="checkbox"/> EPA 3550 <input type="checkbox"/> EPA 1310	<input checked="" type="checkbox"/> EPA 8080.3 <input type="checkbox"/> EPA 8270 <input type="checkbox"/> EPA 680
Oil	<input type="checkbox"/> EPA Test Method "The Determination of Polychlorinated Biphenyls in Transformer Fluid and Waste Oils."	

ANALYST Dma

ATTACHMENT B-4
DIOXIN ANALYSES



December 23, 1987

Mr. Ken Wahl
Canonie Environmental
212 Frank West Circle
Suite A
Stockton, CA 95206

Dear Mr. Wahl:

Please find attached results of analysis performed on two samples submitted 11/22/87 for 2,3,7,8-TCDD.

The samples for 2,3,7,8-TCDD were prepared and analyzed according to the Statement of Work for Rapid Turnaround Dioxin Analysis, Revision 6/19/87, method HRGC/LRMS for solid samples.

If you have any questions or need further clarification, please do not hesitate to call.

Thank you for choosing metaTrace for your analytical services.

Respectfully Submitted,

Denise A. Asher
Environmental Project Manager

DA

Enclosure

CERTIFICATE OF ANALYSIS

PREPARED FOR: CANONIE ENVIRONMENTAL PN 104-01AP
212 FRANK WEST CIRCLE
SUITE A
STOCKTON, CA 95206

PROJECT NUMBER: 87-903

DATE RECEIVED: 12/22/87

SAMPLE NUMBER:	AA07254	AA07255
SAMPLE IDENTITY:	1011 722139	1011 722140

<u>PARAMETER</u>	<u>DETECTION</u> <u>LIMIT</u> <u>NG/GM</u>		
2,3,7,8-TCDD	0.300	< 0.300 NG/GM	< 0.300 NG/GM

metaTRACE, Inc.

Chain-of-Custody

Page 1 of 1 Cust.

Client: CANONIC Environmental

Project No: 104-01AP

Due Date: 12-23-87 Report To: D. ASHER

Date Received: 12/22/87

Received By: Coli Kennedy

Sample Location: O Coles #2

ANALYSIS

ITEM NO.	SAMPLE NO.	SAMPLE ID/ DESCRIPTION	MATRIX	SAMPLE DATE	CONTAINER/ PRESERVATIVE	ANALYSIS												COMMENTS	DISPOSAL	
						3373 TCDD	Dioxin	Quin. ST											NORM	HAZ
1	AA07254	1011-722139	Solid	12/21/87	16oz 4 ¹ / ₂ g / Cold	✓	✓	✓										See ATTACH 11 & 12 pages		
2	AA07255	1011-722140	↓	↓	↓	✓	✓	✓										↓ RAPID Response Dioxin, TCDD		
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18																				

ASHE

metaTRACE

Extract Chain-of-Custody

Project # 104-01Analysis TCDD

Sample No	Wt/Vol	Extract Volume	Date	Initials	Conc To	Date	Initials	Clean-up	Date	Initials	Conc To	Date	Initials	Comments
AA07254	10.14	75ml	12-22-87	DC	5ml	12-22-87	DC	PER METHOD	12-22	DC	DRY	12-22	DC	
7255	10.42													
BLK 220														
Spike Compounds		Amounts	Surrogate Compounds		Amounts	From	Date	Received		Date				
			Spiking II		100ul	Mark Q. Barkin	12/22/87	J. D. Lundy		12-22-87				

Analysis Date:

[illegible]

White Sample:

Pink L&D Copy

ATTACHMENT B-5
PCB COMPOSITION (CHEMEX)

CHEMEX

Labs Alberta (1984) Ltd.

A. Montgomery
Canonie
Denver, Colorado

FAX# 303-799-0186

SUBJECT- Regarding our recent PCB analysis.

- I have enclosed the chromatograms of our standard and the sample in question.
- There are a few extraneous peaks in the sample chromatogram particularly at the back end which are likely heavy oil components.
- You will notice that we have subtracted the peak @ 6.088 minutes from the total peak area as it was uncharacteristic of 1242.
- If there appears to be a mass balance problem it is likely due to the following:
 1. loss of PCB during the test, via the gas stream or coating on the collection lines.
 2. analytical error
 - the GC/ECD is extremely sensitive to PCB and at the same time has a very narrow linear range. The sample in this case was diluted 31,000 times to obtain an "onscale" chromatograph. This large dilution factor could affect the final result significantly.
 3. sample homogeneity
 - although the sample was thoroughly mixed, it is a three phase mixture. Approximately, 1 gm of sample was removed from the 500 ml container during mixing to be used for subsequent analysis. Inability to obtain a true representative sample is a possibility.

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CHEMEX

Labs Alberta (1984) Ltd.

Analytical Procedure

-After the material is subsampled, it is treated with cold H₂SO₄ for 20 minutes to destroy interfering organics. This mixture is then diluted with hexane and placed in an ultrasonic extractor for 10 min. The solvent is filtered, and diluted to a known volume prior to injection into the GC/ECD.

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ESTEVAN, SASK. Apex Analytical Laboratories Ltd., 483 Devonian St., Estevan, Canada Tel: (403) 844-1111

CHEMEX

Labs Alberta (1984) Ltd.

Comparison to PCB procedure for UMATAC Samples to EPA608.

- EPA608 is used for organo-chlorinated pesticides as well as PCB.
- 608 is intended for use at "trace" levels.
- 608 uses a florisil cleanup whereas we incorporate a H2SO4 ash.
- 608 uses GC/ECD with packed columns and dual column confirmation, our method employed GC/ECD single column 30m capillary columns.

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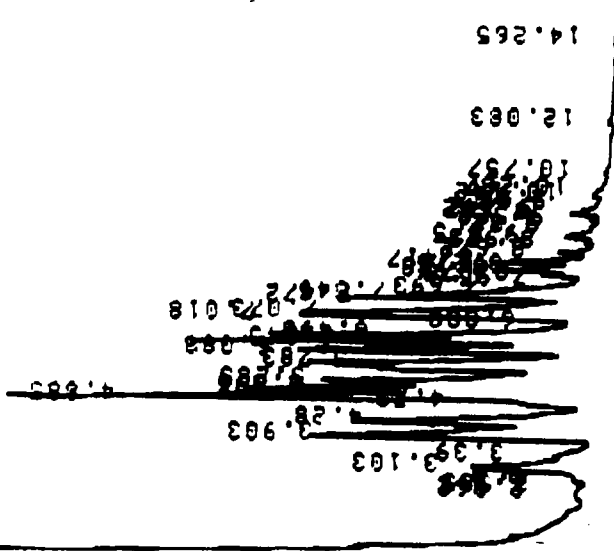
#106, 6502 - 112th Street, Grande Prairie, Canada T6V 6X4 Tel.: (403) 632-0227

10509 - 98 Street, High Level, Canada T0H 1Z0 Tel.: (403) 926-2448

Apex Analytical Laboratories Ltd., 483 Devonian St., Estevan, Canada Tel: (306) 634-9112

START
08/00/29

01:26:37



CHROMATOPAC C-R3A
SAMPLE NO 0
REPORT NO 4372
FILE METHOD 0041

PXNO TIME AREA MK IDNO CONC NAME

1	2.362	1037	V	3.8271	0.32
2	3.103	12397	V	0.9213	
3	3.39	2984	V	7.961	
4	3.903	25788		7.0702	
5	4.28	22903	V	0.9619	
6	4.73	3116	V	11.1266	
7	4.885	36042	V	6.0717	
8	5.095	19668	V	8.0793	
9	5.285	26171	V	10.292	
10	5.783	33339	V	7.0276	
11	6.088	22764	V	5.891	
12	6.345	19083	V	5.9706	
13	6.495	19340	SV	4.6594	
14	7.018	15093	V	6.5902	
15	7.073	21348	V	3.5076	
16	7.472	11362	V	2.5722	
17	7.545	8332	V	1.7347	
18	7.693	5619	V	0.6011	
19	8.075	1947	V	1.169	
20	8.188	3787	V	0.6999	
21	8.275	2267	V	1.4561	
22	8.417	4717	V	0.5674	
23	8.672	1938	V	0.6841	
24	8.957	1957	V	0.3179	
25	9.692	1030	V		
TOTAL					108
323930					

1242
1.312 ppm

CHROMATOPAC C-R3A
 SAMPLE NO 0
 REPORT NO 4317

FILE 0
 METHOD 0041

P<NO TIME AREA MK IDNO CONC NAME

P<NO	TIME	AREA	MK	IDNO	CONC	NAME
1	3.805	23192			5.2057	
2	4.133	17928	V		4.0241	
3	4.698	36649	V		8.2263	
4	4.857	16005	V		3.5925	
5	5.022	22680	V		5.0909	
6	5.402	47451	V		10.6589	
7	5.737	38478	V		6.8412	
8	5.952	23047	V		5.1732	
9	6.088	88263	V		19.8117	
10	6.603	57811	V		12.9763	
11	6.937	14716	V		3.3032	
12	6.988	23363	V		5.244	
13	7.272	1566	V		0.3514	
14	7.513	13239	V		2.9716	
15	7.698	12907	V		2.8971	
16	7.902	3781	V		0.8486	
17	8.12	1837			0.4124	
18	8.268	5818	V		1.3059	
19	8.628	4781			1.0732	
TOTAL		445311			100	
START		401,379				

$$\frac{401,579}{299,009} \times 14.512 \times \frac{2.5}{22.6620} = 61,335 \text{ pp}$$

#6
 31,000 x

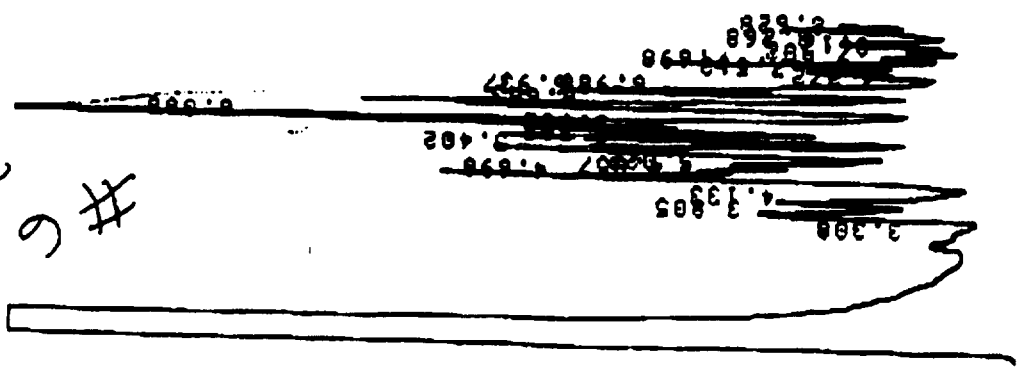


TABLE B-1

PCB MATERIAL BALANCE ON SAND
(SOLID IN Mg/kg: LIQUIDS IN Mg/l)

	<u>Wt. Gms</u>	<u>Vol. ccs</u>	<u>PCB, ppm</u>	<u>PCB, qms</u>
Feed	3,711.7			
			26,457	98.2
		Rerun	28,900	107.3
Res. A				
Oil	21.6	24.0	16,681	0.4
Water	502.4	502.4	114	0.06
Sludge	Trace		10,223	0.10
Res B.				
Oil	64.1	49.3	959,170	47.3
Water	32.1	32.1	12	0.0
Char	2,990.2		<.1	
Ash	2,960.1		<.1	
Gas	43.9			
Total in	98.2 gms			
Total out	47.9 gms			
Accountability	49%			
(Feed Rerun)	45%			

NOTE: Specific gravities Light Oil 0.9
PCB Oil 1.3

TABLE B-2

PCB MATERIAL BALANCE ON MUCK
(SOLID IN Mg/kg: LIQUIDS IN Mg/l)

	<u>Wt. Gms</u>	<u>Vol. ccs</u>	<u>PCB, ppm</u>	<u>PCB, gms</u>
Feed	1,212.9	933	61,335	57.25
		Rerun	16,866	15.74
Res A.				
Oil	3.6	4.0	50,877	0.20
Water	602.9	602.9	70	0.04
Sludge	10.5	8.1	5,492	0.04
Res B.				
Oil	110.9	86.3	235,308	20.07
Water	44.3	44.3	16	0.00
Char	322.8		<.1	
Ash	318.1		<.1	
Gas	34.7			
Total in	57.23 gms			
Total out	20.35 gms			
Accountability	36%			
Accountability	129%			
		(Feed Rerun)		

NOTE: Specific gradities Light Oil 0.9
PCB Oil 1.3

(

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APPENDIX C
PATENT

United States Patent [19]

Taciuk

[11] 4,306,961

[45] Dec. 22, 1981

[54] PROCESS FOR RECOVERY OF
HYDROCARBONS FROM INORGANIC
HOST MATERIALS

[75] Inventor: William Taciuk, Calgary, Canada

[73] Assignee: Alberta Oil Sands Technology and
Research Authority, Edmonton,
Canada

[21] Appl. No.: 158,068

[22] Filed: Jan. 9, 1980

Related U.S. Application Data

[60] Division of Ser. No. 91,910, Nov. 6, 1979, which is a
continuation-in-part of Ser. No. 34,098, Apr. 27, 1979,
abandoned, which is a continuation of Ser. No.
828,119, Aug. 27, 1977, abandoned, which is a con-
tinuation-in-part of Ser. No. 603,044, Aug. 8, 1975,
abandoned.

[51] Int. Cl. C10C 1/00

[52] U.S. Cl. 208/11 R

[58] Field of Search 208/11 R, 8 R

[56] References Cited

U.S. PATENT DOCUMENTS

2,664,389 12/1953 Rex et al. 208/11 R

3,481,720 12/1969 Bennett 208/11 R

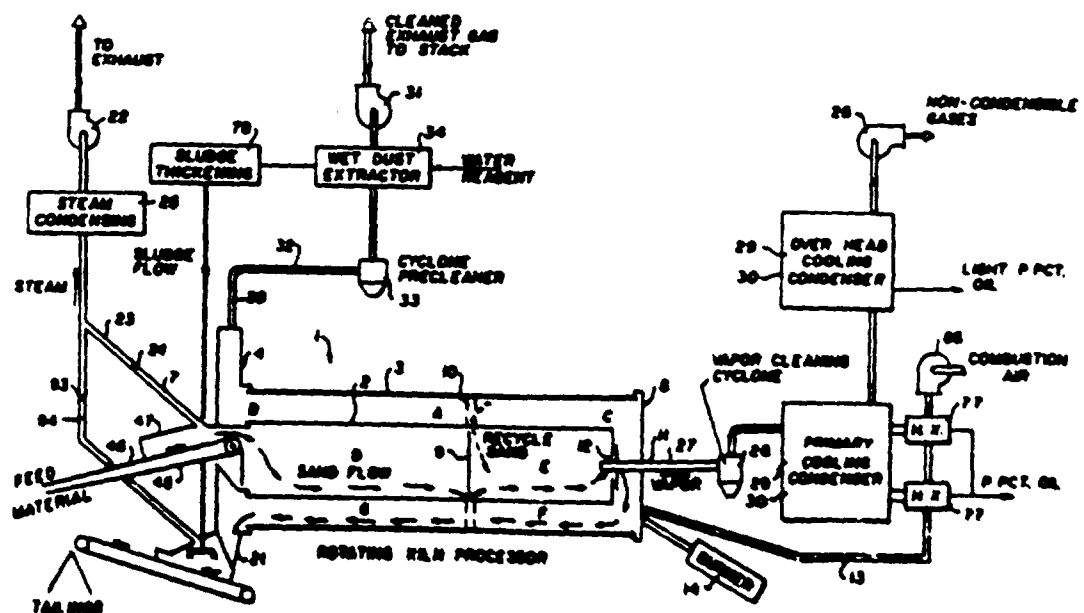
Primary Examiner—T. M. Tufariello
Attorney, Agent, or Firm—E. P. Johnson

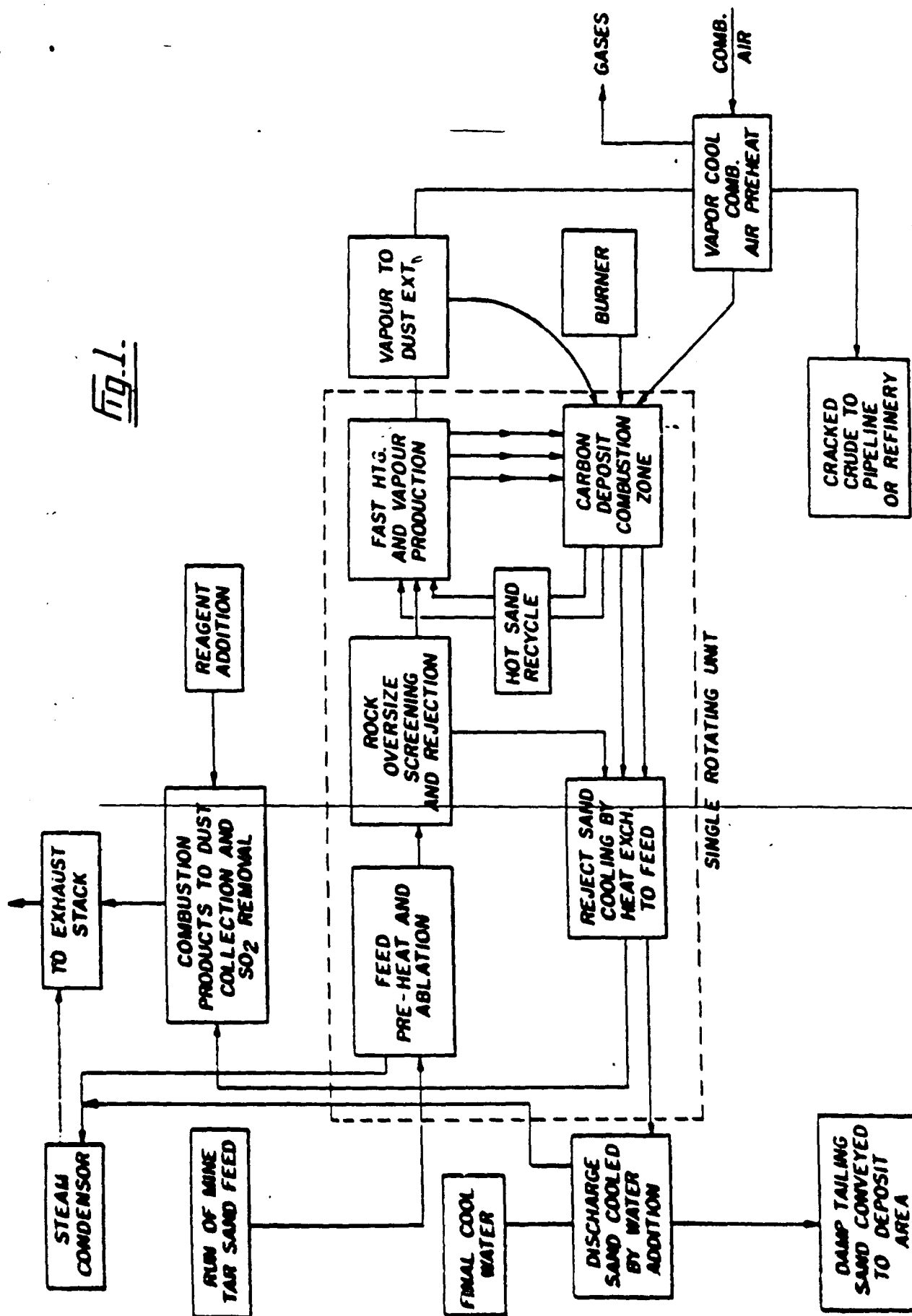
[57] ABSTRACT

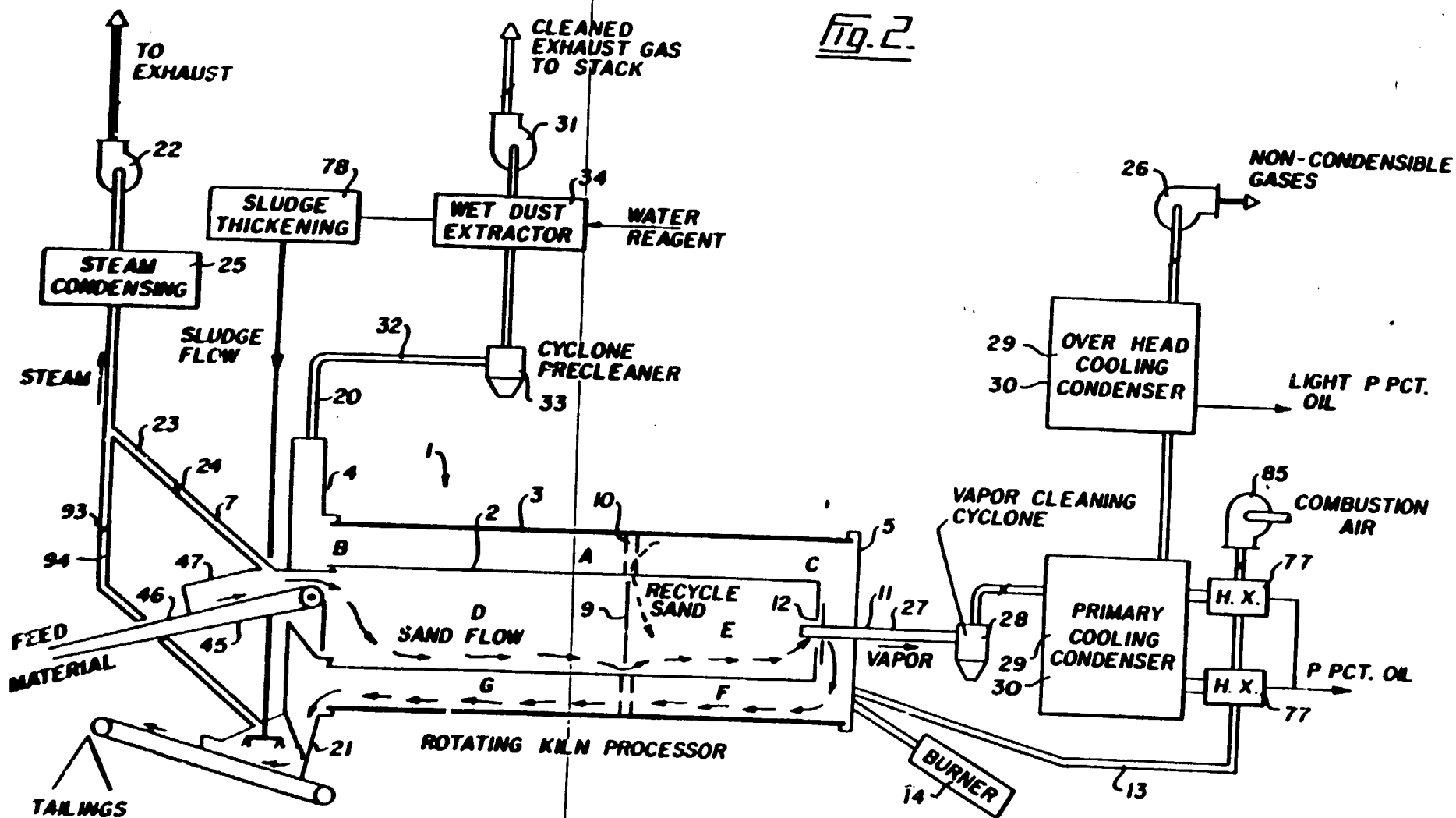
A dry thermal processor is provided for recovering

hydrocarbons from oil sand solids. The processor comprises concentric, radially spaced, horizontal inner and outer tubular members connected for rotation together. The inner member provides a substantially open preheat zone and vaporization zone while the outer member provides, in the annular space between the tubular members, a substantially open combustion zone and heat transfer zone. The ends of the outer member are sealed by stationary feed end and product end structures. Advance means move the oil sand solids from the feed end structure through the preheat and vaporization zones to the product end structure and back through the combustion and heat transfer zones. In the preheat zone the oil sands are progressively heated and dehydrated by heat transferred through walls of the inner member from hot solids being dropped thereon in the heat transfer zone. Rotation of the inner member causes size reduction of the oil sand feed in the preheat zone. Oversize is discharged directly into the annular space at the second end of the preheat zone. In the vaporization zone, the preheated oil sands are mixed with hot solids recycled from the combustion zone to thereby vaporize the hydrocarbon content of the oil sands and produce a coke residue on the sands. These coked sands are transferred into the combustion zone where they are struck by air to support combustion of the coke. This combustion together with supplemental heat provide the heat requirements of the processor.

4 Claims, 18 Drawing Figures







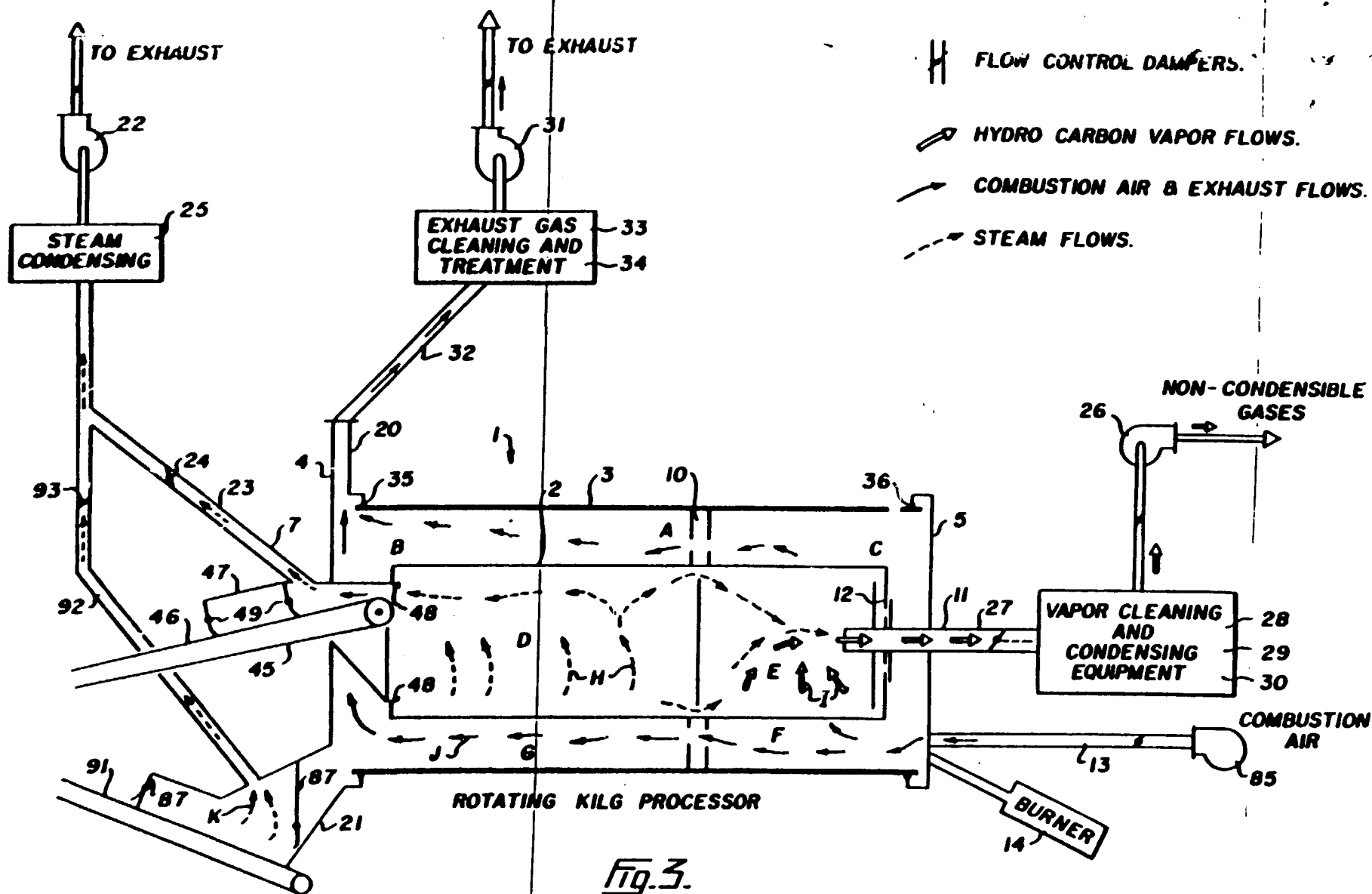


Fig. 3.

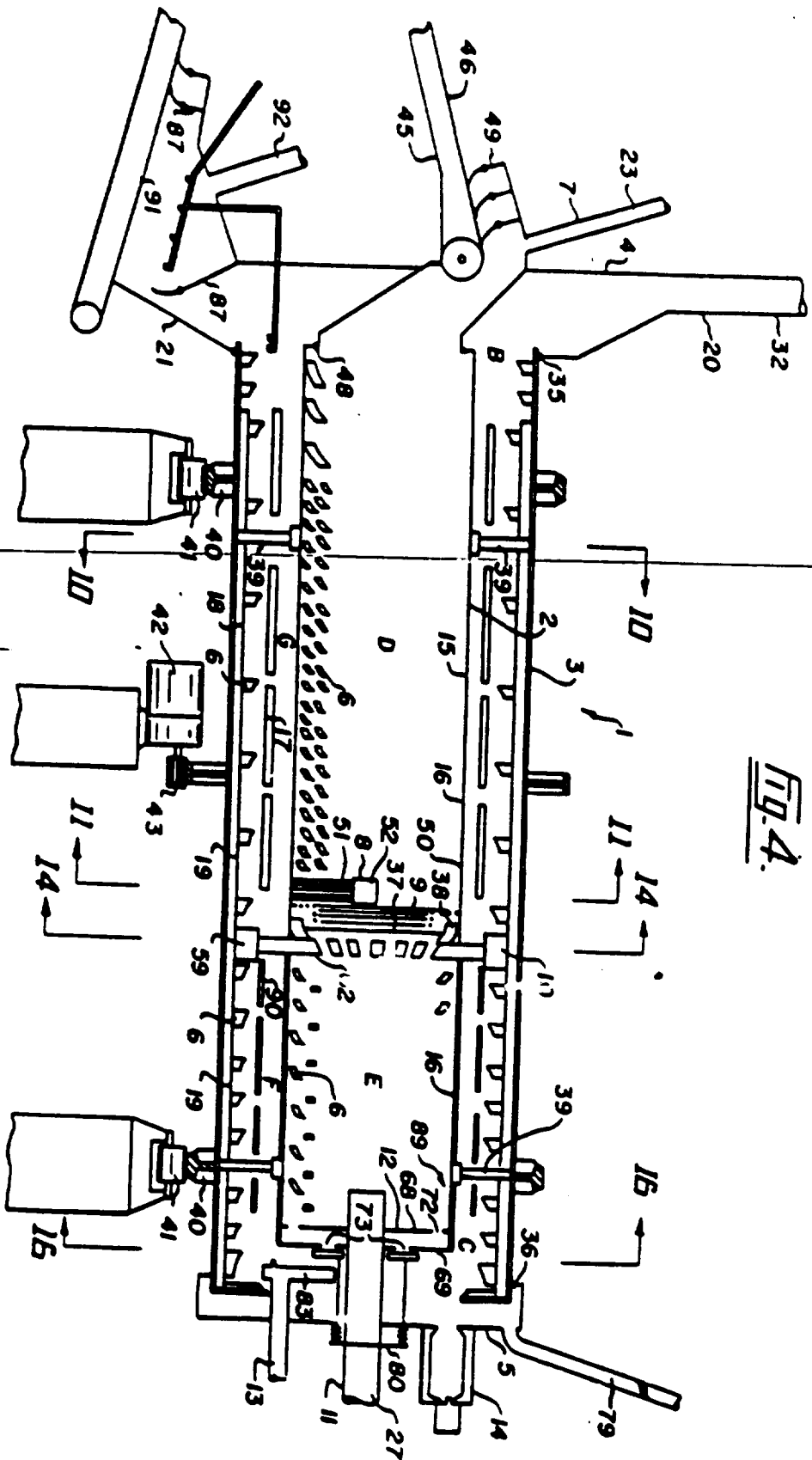


Fig. 4.

Fig. 5. INNER PREHEAT ELEMENTS.

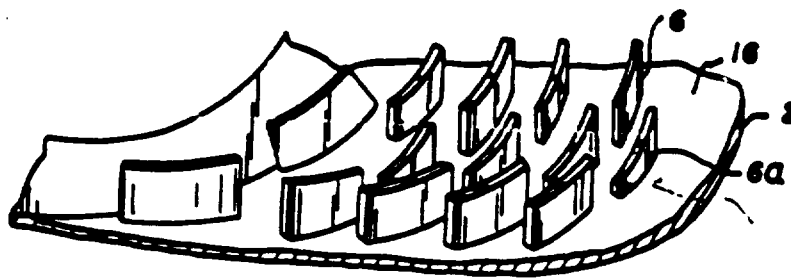


Fig. 6. VAPOR ZONE ELEMENTS.

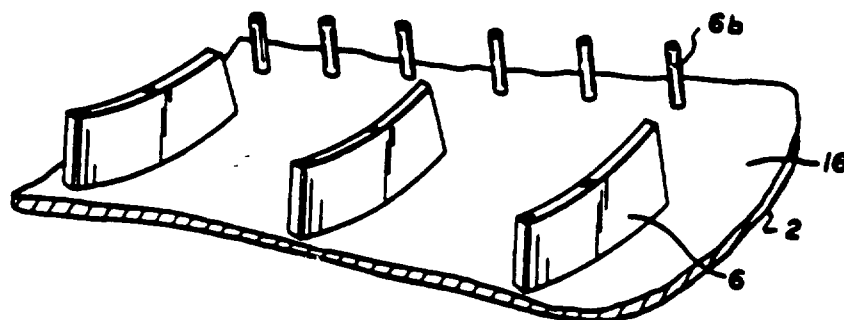


Fig. 7. COMBUSTION ZONE ELEMENTS.

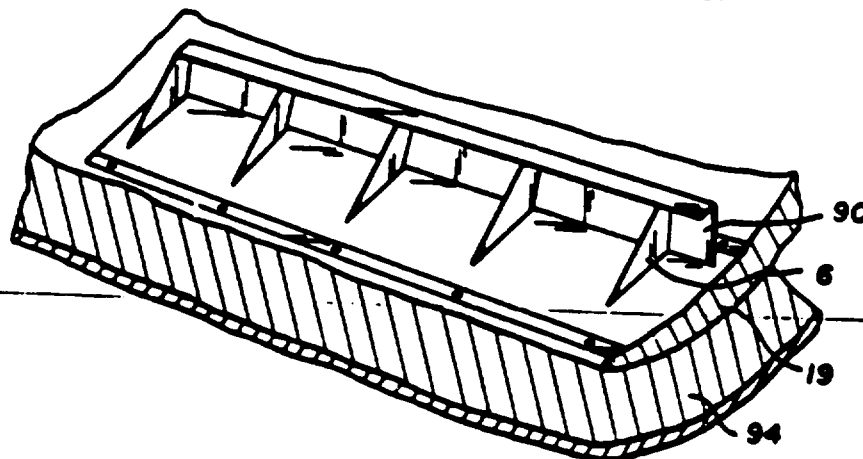
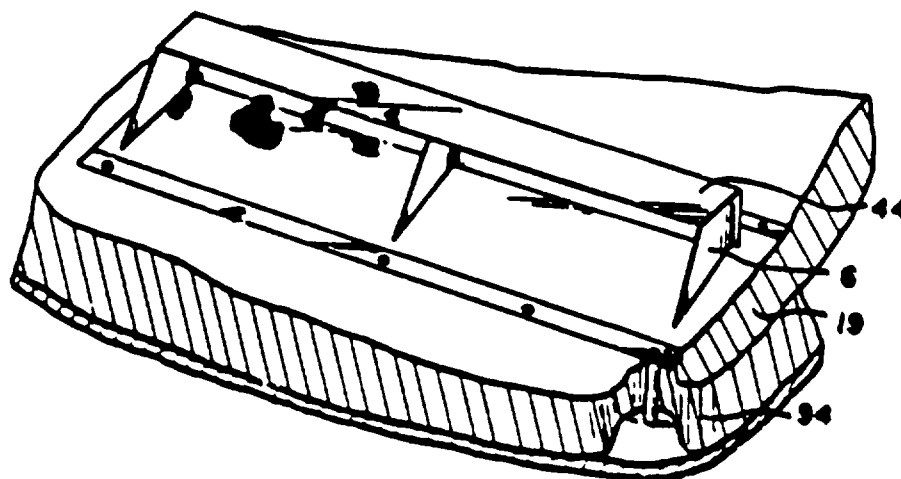


Fig. 8. OUTER PREHEAT ELEMENTS.



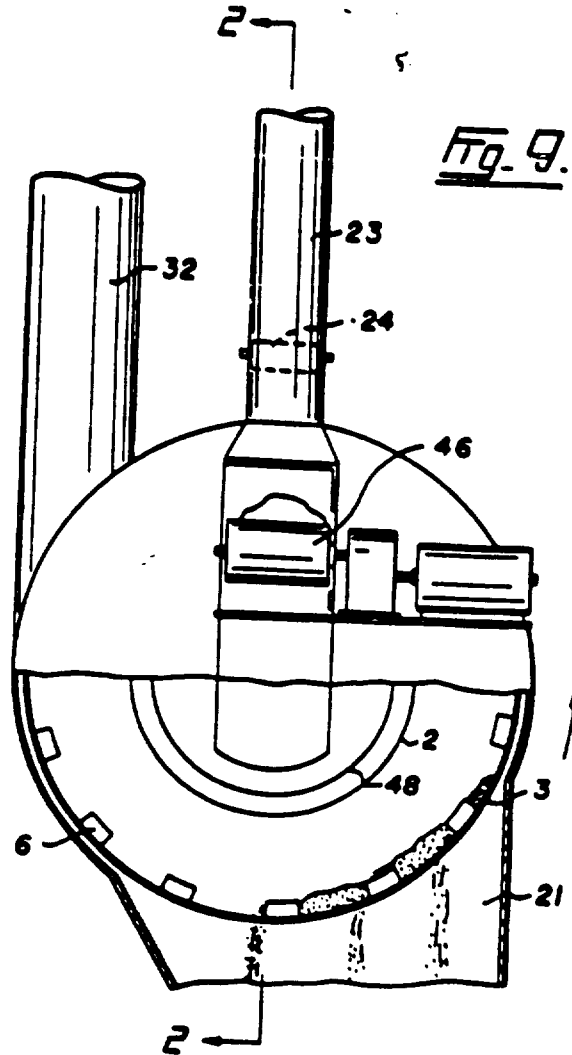


Fig. 10.

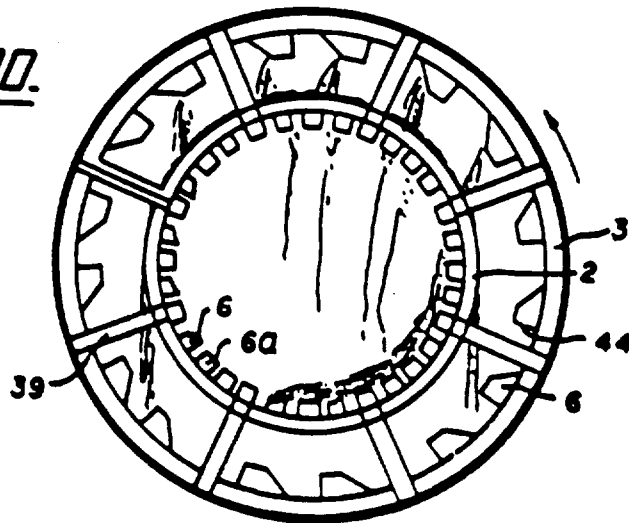


Fig. 11.

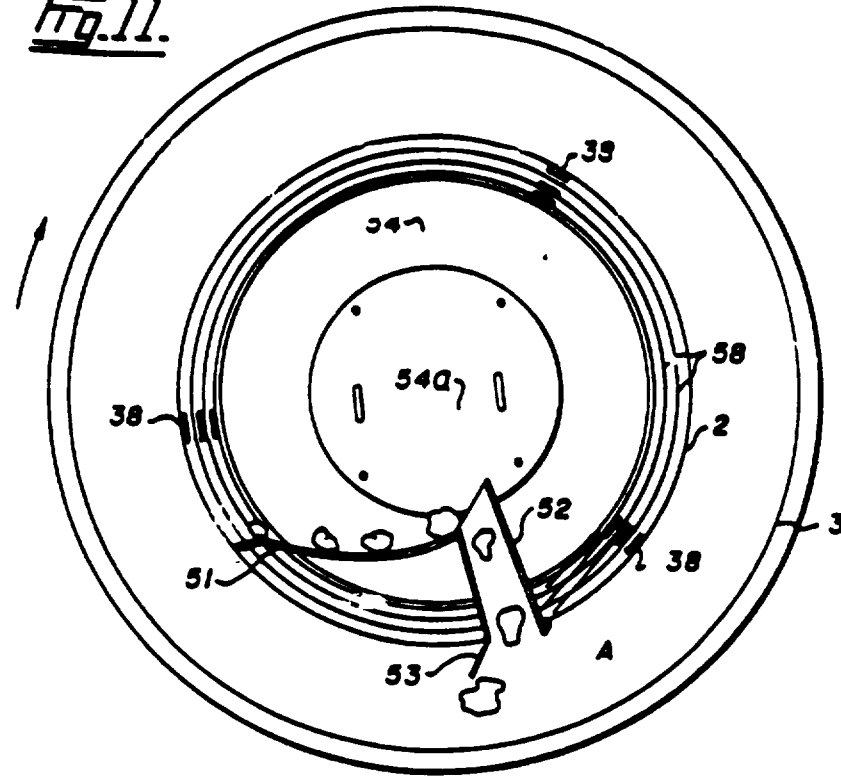
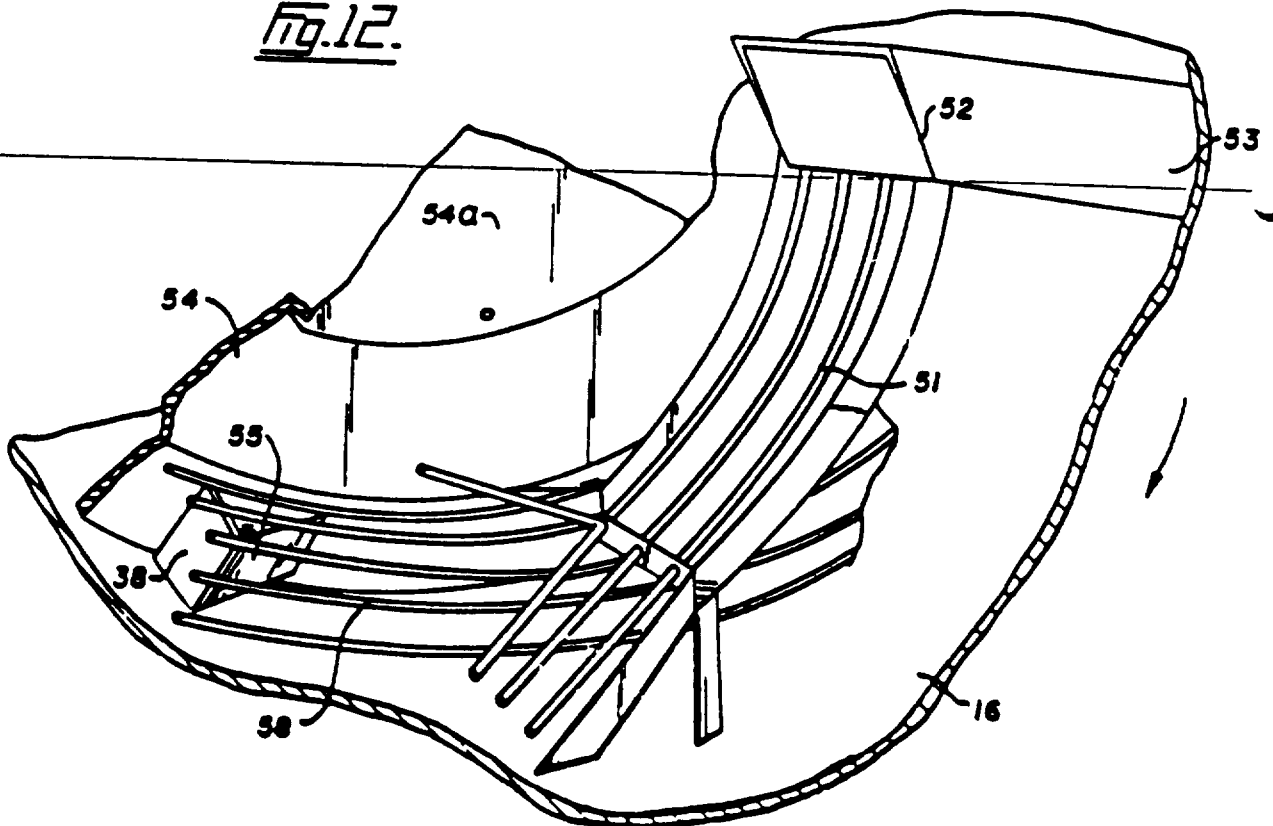
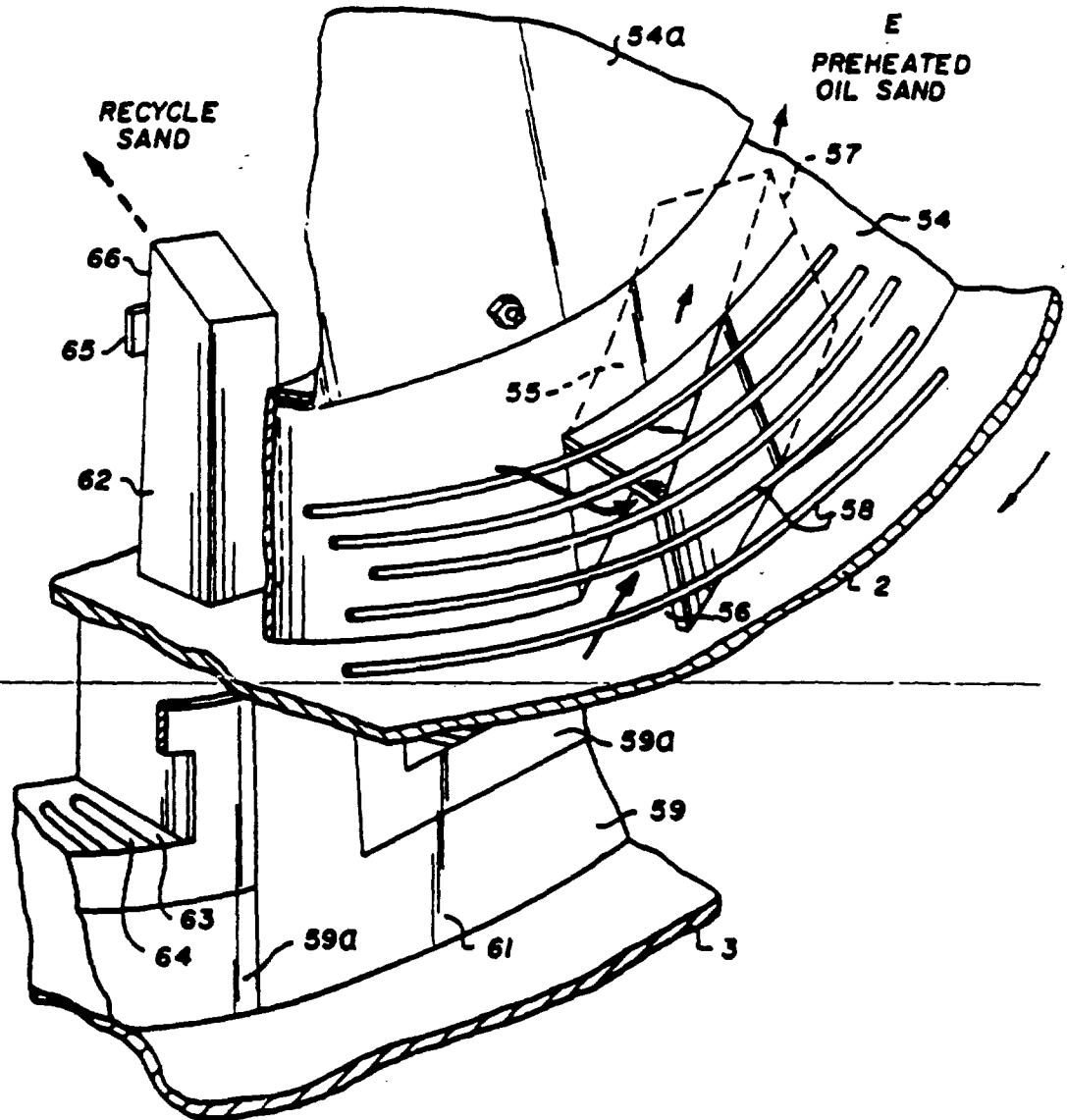


Fig. 12.

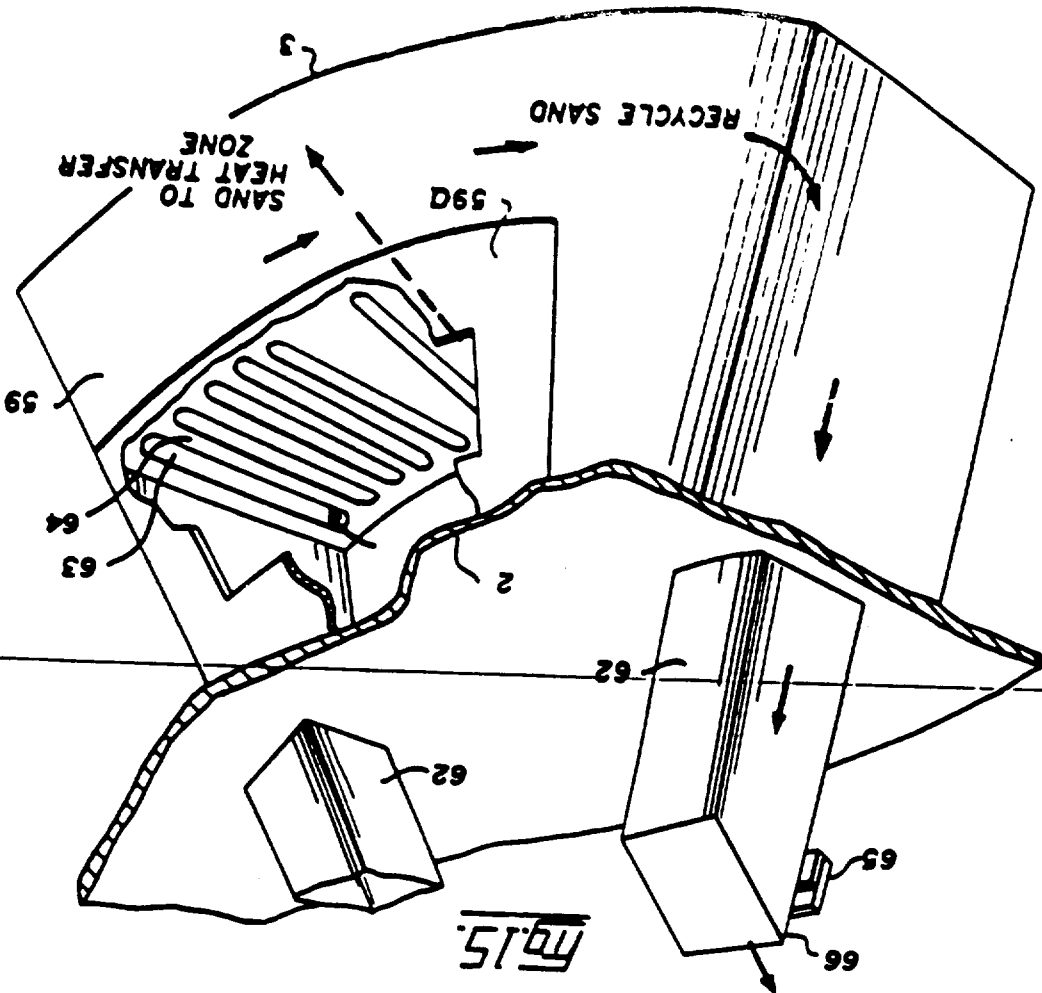
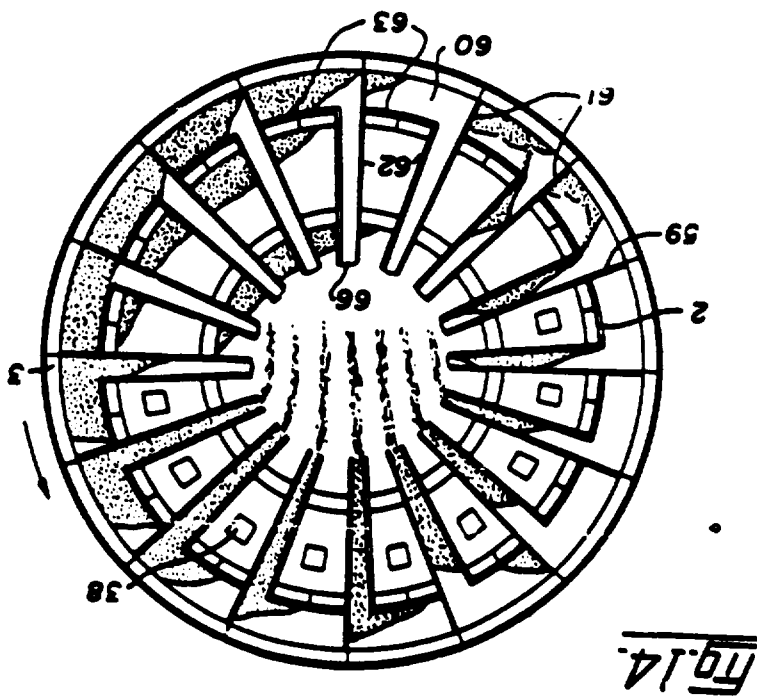


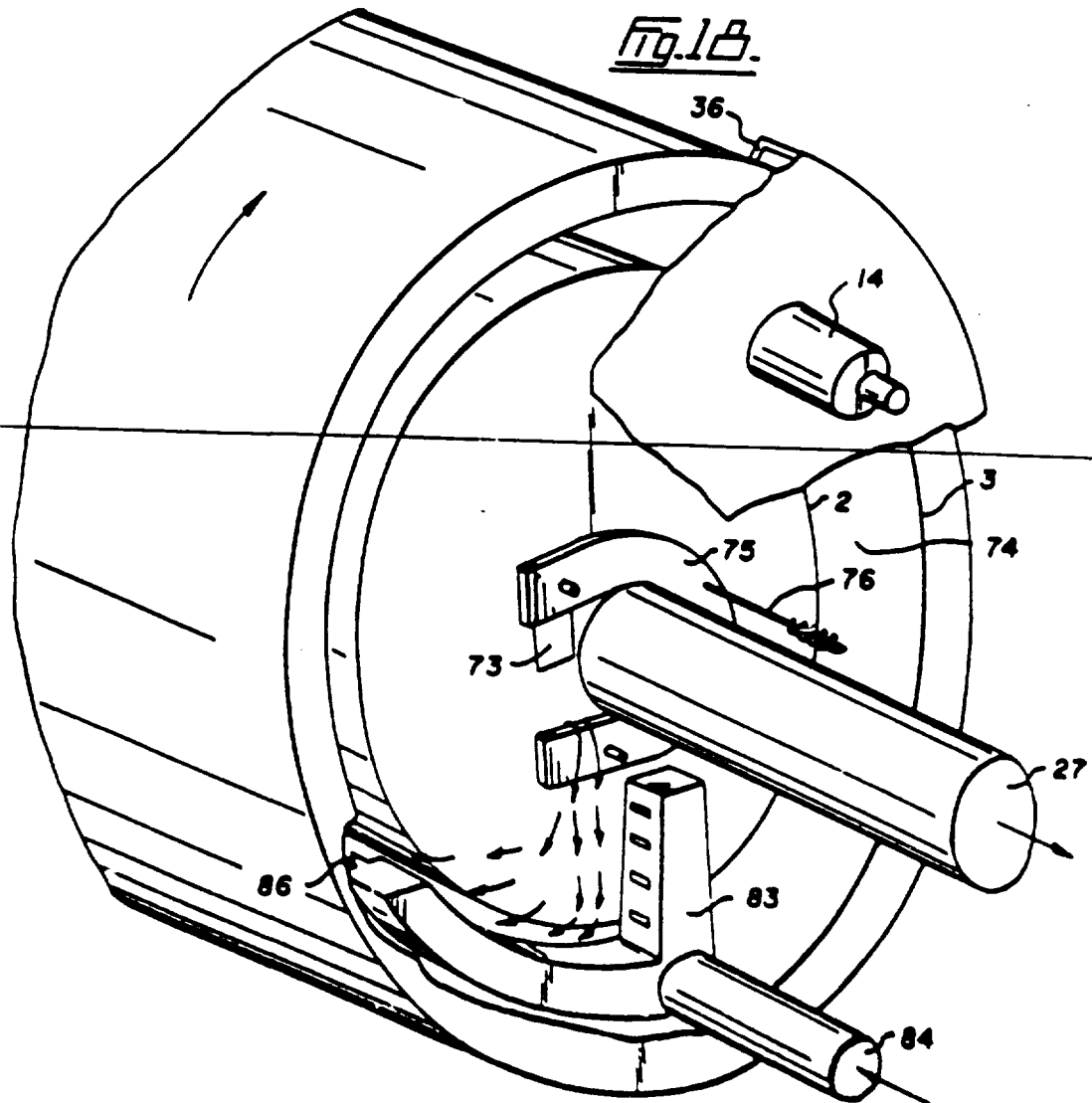
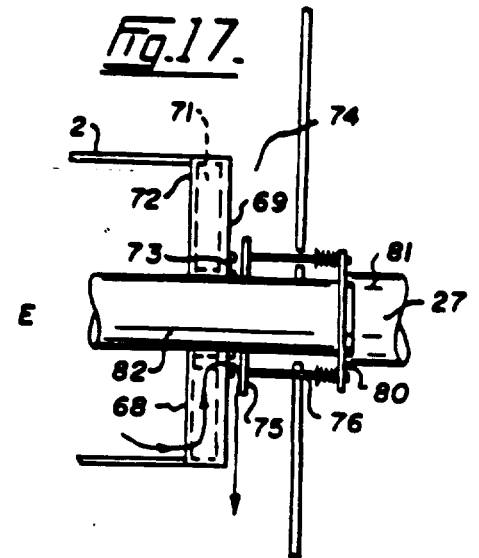
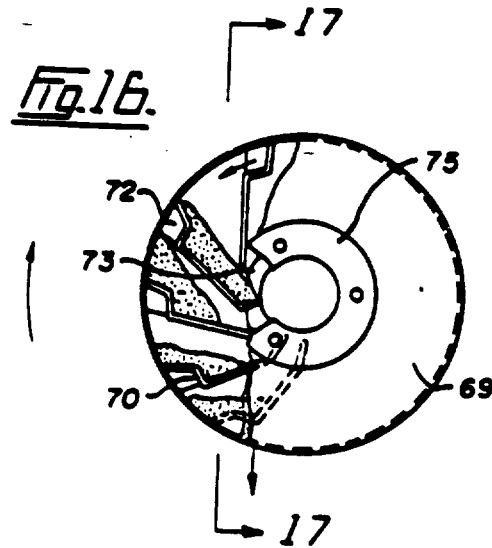
4
3
0
6
9
6
1

Fig. 13.



696034





PROCESS FOR RECOVERY OF HYDROCARBONS FROM INORGANIC HOST MATERIALS

This is a divisional of application Ser. No. 091,910, filed Nov. 6, 1979, which is a Continuation-In-Part of prior application Ser. No. 034,098, filed Apr. 27, 1979, now abandoned, which is a Continuation of application Ser. No. 828,119, filed Aug. 27, 1977, now abandoned, which is a Continuation-In-Part of the parent application Ser. No. 603,044, filed Aug. 8, 1975, now abandoned.

FIELD OF THE INVENTION

This invention relates to a dry method and apparatus for recovering hydrocarbons from a material such as oil sand.

BACKGROUND OF THE INVENTION

As is further discussed below, the invention is not limited in application to oil sand; however it has been developed in connection with the treatment of such material and therefore the following disclosure describes it in connection with that particular feedstock.

Whole oil sand is a material whose composition and characteristics have direct influence on the design of apparatus and method for treating it. Its composition includes granular mineral solids, water and bitumen. The granular solids comprise coarse solids (mainly sand having particle sizes in the range 80-200 mesh) and fine solids (mainly clay having particle sizes less than about -44μ). The whole oil sand further comprises rocks, ranging from pebbles to boulders, and cohesive lumps of granular solids. In winter, the whole oil sand, which is mined by huge draglines or rotating bucket wheels, commonly reports in the form of frozen chunks—some weighing in the order of two tons. In summer, the as-mined material reports as a sticky mass which is difficult to screen to remove the oversize rocks and lumps. When used herein, the term "whole oil sand" means this as-mined material, although it may have been subjected to preliminary rough screening or the like to remove easily separable large boulders.

Oil sands are today commercially treated with what is commonly known as the hot water extraction process. This process involves first conditioning the whole oil sand by mixing it with steam and some hot water for a period of time in a horizontal rotating drum. With heat and dilution, the solid and hydrocarbon components of the oil sand separate to an extent which permits oversize material to be removed by screening. The product is then diluted with hot water and introduced into a settling tank. Here the coarse sand settles out and is discarded as an underflow. The bitumen, attached to air bubbles incorporated in the mixture in the conditioning drum, floats as a froth and is recovered. A dragstream—containing mainly water, some non-floatable bitumen, and fine solids—is drawn from the centre of the tank. This dragstream is treated in a sub-aerated flotation cell to produce a contaminated bitumen froth and a watery underflow. The underflows are combined and discarded; the froths are combined, cleaned to remove contained water and solids, and then upgraded in a conventional refinery on-site operation.

There are presently two commercial plants of this type in operation in Canada. The second-built plant is designed to produce about 125,000 barrels of net synthetic crude per day and its construction cost, including

the mining and upgrading facilities, was in the order of several billions of dollars.

There are a number of disadvantageous features, of interest with respect to this invention, which characterize the hot water extraction process. For example, it uses enormous quantities of water. Since it is intended to produce a million or more barrels of product per day from the Canadian oil sands, the pressure on the finite water supplies in the oil sand area is a serious problem. Secondly, the wet tailings produced have to be retained for years in gigantic diked ponds before the water in them is sufficiently clean to be re-used in the process. This is because the clay particles suspended in the water are very slow to settle out. Thirdly, the need to heat process water and produce steam consumes some of the hydrocarbons produced. Fourthly, there is a need to upgrade the bitumen with an on-site refinery before it can be pumped, due to its high viscosity.

With these disadvantages in mind, it has heretofore been proposed to pyrolyze the oil sand using a solid carrier to provide the heat. More particularly, this "dry" scheme contemplates mixing oil sand with hot recycled sand, thereby effecting heat transfer and vaporizing and cracking bitumen and producing coked sand. The coke on the coked sand is subsequently burned to heat the sand so that it may be recycled to the heat transfer operation.

This dry scheme reduces water consumption and disposal. It has the possibility of yielding higher liquid hydrocarbon recoveries than the hot water process including refining. Furthermore, it will yield a less viscous liquid product which will be more easily pumpable than the hot water process product.

This invention is concerned with a novel dry processor and with the process performed in it.

The present processor has been developed with the following criteria in mind. It should be capable of doing the following:

1. processing whole oil sand without or with minimal prior screening;
2. converting whole oil sand into a form from which oversize rocks may be separated and rejected and then making such a separation;
3. reducing the size of lumps of oil sand so that at least some of them become part of the normally processable feed stream;
4. heating the material in stages so as to vaporize the water and hydrocarbons in different zones, with the result that they may be separately recovered and thus do not contaminate each other to an undesirable extent;
5. vaporizing and cracking hydrocarbons so that they may be withdrawn and collected in a desirable product form;
6. conserving energy by burning coked sand to provide some, if not all, of the heat needed for the process in the form of hot sand, from which heat may be extracted by heat transfer;
7. efficiently recovering heat from recycled hot sand to further conserve energy; and
8. carrying out these operations in a single processor unit which is capable of maintaining substantial segregation of the gaseous atmospheres in the various zones where different operations are simultaneously processing.

Bennett, in U.S. Pat. No. 3,481,720, describes a dry thermal processor which meets some, but not all, of these objectives. This processor was developed in connection with treating oil shale, but the patent states it

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has utility for oil sand as well. The Bennett unit comprises rotatable, horizontal, concentrically arranged, spaced inner and outer tubes having first and second ends. The inner tube provides a preheat zone at its first end and a vaporization zone at its second end. The annular space between the tubes is divided into a combustion zone at the second end and a heat-transfer zone at the first end. The feed is pre-crushed and then advanced through the pre-heat, vaporization, combustion and heat-transfer zones sequentially and undergoes different processes as described below. In general, the method embodied in the operation of the unit comprises:

(a) feeding crushed raw feed stock into the pre-heat zone. Here the feed is heated to about 200°-300° F. by heat exchange, through the inner tube wall, with hot gases associated with hot solids advancing through the heat-transfer zone of the annular space. By preheating the raw feed, contained moisture is converted into steam, which is recovered through a pipe extending into the preheat zone;

(b) Mixing the preheated feed with hot recycled solids in the vaporization zone and effecting heat exchange through solids contact to produce a mixture having a temperature in the order of 900° F. As a result of this operation, contained hydrocarbons are volatilized, some are cracked, and the gaseous products are recovered from the zone through a pipe extending thereinto—also, coked solids are left as a residue;

(c) Transferring the coked solids into the combustion zone and mixing them with injected air to effect combustion of the coke and raise the temperature of the solids to 1400°-1600° F.;

(d) Recycling a portion of the hot solids produced in the combustion zone into the vaporization zone to heat the preheated solids and advancing the balance of the hot solids past the recycle point and through the heat-exchange zone, to heat the wall of the inner tube and thus the solids contained therein in the preheat zone; and

(e) Discharging the solids from the first end of the heat-exchange zone to waste.

Bennett teaches the use of augers to advance the solids through the inner tube and back through the annular space. The augers are welded around their inner and outer circumferences to the relevant containing tube. By a combination of these augers and a choking action using feed solids (achieved by varying the pitch of the augers), Bennett segregates the preheat zone gases, the vaporization zone gases and the combustion zone gases from each other.

With respect to the objectives previously set forth, it will be noted that Bennett relies on:

(1) Augers to move the material. This requires that the feed stock be of generally uniform particle size. Bennett achieves this by requiring crushing of the feed-stock before it is introduced into the processor;

(2) The augers and solids choking to achieve segregation of the gaseous atmospheres; and

(3) The use of gases in the heat-transfer zone to conduct heat from the recycled hot solids in the zone to the wall of the inner tube for conductance through the wall to the solids in the pre-heat zone.

SUMMARY OF THE INVENTION

The present invention provides a dry processor in which features have been combined to enable the unit to successfully process whole oil sand.

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Like Bennett's unit, the present processor comprises spaced, substantially horizontal, generally concentric inner and outer tubular members having first and second ends. The members are connected for rotation together and means are provided for rotatably supporting them and sealing the ends of the outer member and the first end of the inner member. Further means are provided for rotating the members. The inner tubular member provides a preheat zone at its first end and a vaporization zone at its second end. The annular space between the members comprises a combustion zone at its second end and a heat-transfer zone at its first end. Means are provided for feeding whole oil sand into the preheat zone. Means are also provided for removing water vapor from the preheat zone. Further means are provided for advancing oil sand solids through the pre-heat and vaporization zones and back through the combustion and heat-transfer zones. Means are provided for removing hydrocarbon gases from the vaporization zone. Means are also provided for transferring coked solids from the vaporization zone to the combustion zone, said means cooperating with the coked solids to prevent significant gas movement therethrough between these zones. Further means are provided for introducing oxygen-containing gas into the combustion zone to react with the coke and effect combustion. Means are further provided for removing combustion gases from the annular space. Means are also provided for recycling a portion of the hot solids produced in the combustion zone back into the vaporization zone, said means cooperating with the hot oil sand solids to prevent significant gas movement therethrough between the annular space and the vaporization zone. Further means are provided for removing oil sand solids from the heat-transfer zone for disposal.

However, the invention is characterized by incorporating into this prior combination at least some of the following novel features:

(1) the preheat and vaporization zones are substantially open spaces, as are the combustion and heat-transfer zones;

(2) separate suction means, which may comprise a fan and conduit means, are provided to withdraw gas from each of the preheat, combustion and vaporization zones, with the greatest suction preferably being drawn on the vaporization zone;

(3) means are provided in the preheat zone for advancing, lifting and mixing the whole oil sand solids by a cascading action to effect size reduction of the oil sand lumps;

(4) means are also provided, at the second end of the preheat zone, for separating oversize solids from the oil sand being treated and removing them from the zone, preferably for discharge into the heat-transfer zone whereby they may subsequently be carried to waste;

(5) means are also provided, downstream of the rock removal means and between the preheat and vaporization zones for restricting the movement of gases between the zones while permitting de-rocked oil sand to be moved therebetween;

(6) means are carried by the outer tubular member in the heat-transfer zone for lifting hot solids advancing from the combustion zone and dropping them onto the outer surface of the wall of the preheat portion of the inner tubular member to effect heat transfer at a desirable rate through the wall, with the result that heat is efficiently transferred from the hot solids to oil sand proceeding through the preheat zone; and

(7) means are provided at the first end of the outer tubular member for cooling and dampening the hot sand solids as they issue from the heat-exchange zone, which means may be located in the annular space, exterior of the processor or in both of these locations.

The processor as described operates in the following manner.

Whole oil sand (from which easily separable large boulders and the like may have been removed by a preliminary screening operation) is introduced into the preheat zone of the rotating inner tubular member. Here the oil sand is heated, preferably to a temperature in the order of 450° F., while it is cascaded due to the rotation of the containing wall. Substantially all of the contained water is vaporized and withdrawn off by means such as a suction fan and conduit. At the same time, lumps of cohesive oil sand are worked and reduced in size by the combination of bitumen viscosity reduction and thawing of frozen lumps due to heating, and cascading, arising from rotation of the inner member. Upon reduction of the bitumen viscosity, oversize rocks and remaining lumps of oil sand may now be separated from the preheated feed by a screening operation, which is conducted at the second end of the preheat zone. These rocks are removed to reduce damage to the processor seals and to avoid plugging of downstream components. Thus, in summary, preheating of sand and bitumen, water vaporization and removal, ablation of lumps, and oversize separation and rejection are effected in the preheat zone.

The remaining oil sand is then advanced through the aforementioned means which permit solids movement from the preheat zone into the vaporization zone, but which restrict gas movement therebetween. Such means may comprise a wall extending transversely across the bore of the inner member at the interface of the preheat and vaporization zones, said wall being apertured around its periphery. The solids and gases both can move through these apertures, but the gas movement is somewhat restricted, relative to what it would be if there were no wall in place. The reason for restricting the gas flow is clarified below.

On entering the vaporization zone, the preheated oil sand (typically having a temperature in the order of 450° F.) is mixed with recycled hot solids from the combustion zone (typically having a temperature in the order of 1100°-1300° F.) to produce a product typically having a temperature in the order of 900°-1050° F. Mixing is obtained in the vaporization zone by a gentle mixing or cascading action produced on the solids by rotation of the inner member in cooperation with the advanced elements. As a result of heating of the oil sand, the bitumen volatiles are vaporized, some cracking takes place, and coked sand is left as the solids product. The gaseous hydrocarbons are withdrawn from the vaporization zone by suitable means, such as a fan and conduit. The major portion of these hydrocarbons may subsequently be condensed in suitable apparatus to yield liquid product.

Coked solids are transferred from the vaporization zone into the combustion zone. Here an oxygen-containing gas, such as air, is introduced and thoroughly mixed with the coked solids to support combustion. Additional heat may be introduced with a burner. As a result, the solids are raised in temperature, for example to 1100° F.-1300° F.

The hot solids from the combustion zone are then advanced through the annular space. A part of these

solids is recycled into the vaporization zone. The balance of the solids enters the heat-transfer zone, where it is lifted and dropped onto the surface of the pre-heat zone section of the inner member wall. This solid-to-solid contact results in efficient heat transfer to the wall. The transferred heat is conducted through the wall to provide the heat requirements for raising the temperature of the oil sand passing through the preheat zone.

Means, such as a fan and conduit, are used to withdraw combustion gases from the annular space.

The extent of suction drawn separately on each of the annular space, the pre-heat zone, and the vaporization zone is preferably controlled to maintain slight pressure differentials between them, thereby ensuring that a small amount of outside air is drawn through the sealing means into the annular space, a small amount of the gases in the annular zone is drawn into the preheat zone, and a restricted amount of the gases in the preheat zone is drawn into the vaporization zone through the apertures of the restrictive wall. In this manner, migration of hydrocarbon gases into the pre-heat zone and the annular space is substantially prevented. As a result, the preheat zone may be open to accommodate whole oil sand feed; the heat-transfer zone may be open so that lifters may be incorporated therein to effect solid-to-solid contact of hot sand with the inner member wall; and the vaporization zone may be open so that adequate mixing by cascading is obtained therein to ensure efficient heat transfer.

Broadly stated, the invention comprises an apparatus for recovering hydrocarbons from whole oil sand containing sand and clay solids in discrete and lump forms, water, bitumen and oversize rocks. Said apparatus comprises spaced, substantially horizontal generally concentric inner and outer tubular members having first and second ends, said members being connected to rotate together, said inner member forming substantially open pre-heat and vaporization zones at its first and second ends respectively, said members combining to form a substantially open annular space between them having a combustion zone at the second end thereof and a heat transfer zone at the first end thereof; means for rotatably supporting the members; means for sealing the ends of the outer member and the first end of the inner member; means for rotating the members; means for feeding whole oil sand into the preheat zone; means for advancing oil sand solids along a path extending through the preheat and vaporization zones and back through the combustion and heat-transfer zones; said outer member carrying means in the heat-transfer zone for lifting hot sand solids being advanced therethrough and dropping them onto at least part of that section of the wall of the inner member which forms the preheat zone to cause heat to be transferred through such wall section, whereby water in the whole oil sand may be vaporized in the preheat zone and whereby lumps of oil sand may be reduced in size by a combination of heating and cascading effected by rotation of the inner member; first means for removing water vapor from the preheat zone; means for separating oversize solids from the whole oil sand being advanced through the preheat zone and transferring them into the annular space for disposal; means carried by the inner member for restricting gas movement between the preheat and vaporization zones while permitting remaining preheated oil sand to be advanced from the preheat zone into the vaporization zone; means for recycling hot sand solids, being advanced through the annular space, into the first

end of the vaporization zone for mixing with oil sand issuing from the preheat zone to raise its temperature and thereby vaporize and crack hydrocarbons and produce coked solids, said means cooperating with the hot sand solids to prevent significant gas movement there-through between the annular space and the vaporization zone; second means for removing gases from the vaporization zone for recovery; means for transferring coked solids from the vaporization zone to the combustion zone, said means cooperating with the coked solids to prevent significant gas movement therethrough between said zones; means for introducing oxygen-containing gas into the combustion zone for burning coke to produce hot sand solids; third means for drawing combustion gas from the annular space for disposal; and means for removing sand solids from the heat transfer zone for disposal.

In a preferred aspect, the invention broadly comprises means for controlling said first, second and third means whereby the pressure in the vaporization zone is less than that in the preheat zone and annular space.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flow sheet of the process and apparatus of the present invention;

FIG. 2 is a schematic drawing of the processor illustrating the flow of solids therethrough,

FIG. 3 is a schematic drawing of the processor illustrating the preferred flow and removal of the gases produced;

FIG. 4 is a sectional view, taken along line 2—2 of FIG. 9, showing the main features of the processor;

FIG. 5 is a fragmentary perspective view of the closely packed advance plates and keying elements in the preheat zone;

FIG. 6 is a fragmentary perspective view of the advance plates and mixing spikes in the vaporization zone;

FIG. 7 is a fragmentary perspective view of the flat-face lifters in association with the advance elements used in the combustion zone;

FIG. 8 is a fragmentary perspective view of the cup-faced lifters and advance elements used in the heat-exchange zone;

FIG. 9 is an end on view, partially in section, of the feed end structure of the processor;

FIG. 10 is a cross sectional view taken along line 10—10 of FIG. 4, of the preheat and heat-transfer zones;

FIG. 11 is a cross sectional view, taken along line 11—11 of FIG. 4, showing the oversize removal means;

FIG. 12 is a fragmentary perspective view of the oversize removal means and the partition wall;

FIG. 13 is a fragmentary perspective view of the partition wall and the recycle means;

FIG. 14 is a cross sectional view, taken along line 14—14 of FIG. 4, showing the recycle means;

FIG. 15 is a fragmentary perspective view of the recycle means;

FIG. 16 is a cross sectional view taken along line 16—16 of FIG. 4, showing the means for transferring coked solids from the vaporization zone to the combustion zone; a portion of the end plate is cut away for further clarification;

FIG. 17 is a cross sectional view, taken along line 17—17 of FIG. 16, showing the product end seal; and

FIG. 18 is a fragmentary perspective view of the product end seal.

DESCRIPTION OF THE PREFERRED EMBODIMENT IN GENERAL

The apparatus of the present invention is a dry thermal processor 1 for producing and separating, from hydrocarbon-containing solids, a hydrocarbon product stream and a solids waste stream. A schematic drawing of the processor in flow sheet form is shown in FIG. 1.

The oil sand feed material is introduced into the processor 1 as whole oil sand. The term whole oil sand refers to the run-of-the-mine oil sand material, such as that obtained from the Athabasca oil sand deposits of Alberta. The material comprises coarse sand, fine clay, bitumen and water. It usually includes a mixture of cohesive lumps, often in a frozen condition, and discrete particles of oil sand. Also included in the whole oil sand are rocks and other mine site debris, some of which are embedded in the cohesive lumps of oil sand.

With reference to FIG. 2, the processor 1 is seen to comprise radially spaced, concentric, substantially horizontal inner and outer tubular members 2,3. The tubular members 2, 3 are generally coextensive and rigidly interconnected for rotation together as a single unit about their common long axis. An annular space A is formed between the walls of the members. Each of the tubular members 2,3 have first ends at B and second ends at C respectively. The inner tubular member 2 provides a preheat zone D at its first end and a vaporization zone E at its second end. The annular space A is divided into a combustion zone F at its second end and a heat-transfer zone G at its first end. It should be understood that the terms first and second ends are used loosely to refer to adjoining expanses within wall portions of the tubular members as defined by the side and end walls of the tubular members 2, 3.

The outer tubular member 3 extends between a stationary feed end structure 4 and a stationary product end structure 5. The feed end structure 4 provides means for sealing the first ends of the inner and outer tubular members 2, 3 while the product end structure 5 provides means for sealing the second end of the outer tubular member 3.

Advancing means 6 are affixed along the inner surfaces of the tubular members 2,3 to advance the solids therein as the tubular members are rotated. In the inner tubular member 2, the solids are advanced toward the product end structure 5; in the annular space A, the solids are advanced back toward the feed end structure 4.

Whole oil sand solids are introduced through the feed end structure 4 into the preheat zone D. As the feed material is advanced through the preheat zone D, it is progressively heated by heat transferred through the wall of the inner tubular member 2. This heat is obtained from hot solids in the surrounding heat-transfer zone G, which solids are lifted and dropped onto the inner tubular member 2. The temperature in the preheat zone is controlled to a level which is sufficient to remove substantially all of the water associated with the feed material without substantial vaporization of the bitumen component of the oil sand material. In the preheat zone D, the solids are cascaded as the containing tubular member is rotated. This cascading action arises from the closely packed advance means 6 and keying element 6a provided in the preheat zone. This preheating, together with the cascading action, reduces

the particle size of the lumps of oil sand material and releases rocks and other debris from these lumps for their subsequent removal. The water vapor and steam from the preheat zone are withdrawn by first gas removal means 7.

Also provided in the preheat zone D is means 8 for separating and transferring oversize solids from the preheated and ablated feed material. This oversize material, which includes rocks, lumps of oil sand material resistant to particle size reduction and other large debris, is dropped into the annular space A for disposal.

Means 9 are provided between the preheat and vaporization zones D, E for restricting gas movement between these zones while permitting the remaining preheated oil sands to be advanced therethrough.

In the vaporization zone E, the remaining preheated solids are mixed with hot recycle solids recycled from the combustion zone F through recycle means 10. The temperature of the preheated solids is thereby rapidly raised to a level sufficient to thermally crack and vaporize a portion of the bitumen component. The hydrocarbon vapors produced are removed as a product by second gas removal means 11 provided at the second end of the inner tubular member 2.

As a result of thermally cracking and vaporizing hydrocarbons in the oil sand material, coked solids particles are produced. These coked solids comprise a coke residue in association with the remaining sand. At the second end of the inner tubular member 2, means 12 are provided for transferring the coked solids from the vaporization zone E into the combustion zone F. These means 12 cooperate with the coked solids to prevent any significant gas movement between these zones E, F.

Means 13 are provided for introducing an oxygen-containing gas, such as air, into the combustion zone F for burning at least part of the coke on the coked solids to produce hot sand solids. This combustion, together with any supplemental heat which may be required, raises the temperature of the sand solids to a level sufficient to cause vaporization in the vaporization zone when such hot solids are recycled. Supplemental heat can be provided by introducing heated air from a burner 14 into the annular space A.

As the combustion-heated solids are advanced toward the feed end structure 4, a portion of such hot solids is recycled to the vaporization zone E as described previously. The remaining combustion-heated solids are advanced back through the heat-transfer zone G.

In the heat-transfer zone G, the hot combustion-heated solids are lifted and dropped onto that section 15 of the wall 16 of the inner tubular member 2, which section forms the preheat zone D. For this purpose, lifting means 17 are provided along at least part of the inner surface of that section 18 of the wall 19 of the outer tubular member 3, which section forms the heat-transfer zone G. Waste heat which would otherwise be lost is thus recovered and transferred to the solids in the preheat zone D.

Combustion produced gases are withdrawn from the annular space A by gas removal means 20 at the first end of the outer tubular member 3.

The sand solids completing travel through the heat transfer zone G are removed from the annular space A by the removal means indicated at 21. The hot sands are thereafter cooled and conveyed to a deposit area.

Segregating and Removing the Gases Produced

The gases and vapors produced as abovedescribed are of three types, namely, the water vapor produced in the preheat zone D, the hydrocarbon gases and vapors produced in the vaporization zone E, and the combustion gases produced in the combustion zone F. For purposes of safety and economics of recovery, these gaseous atmospheres are preferably substantially segregated from each other and withdrawn from the tubular members 2, 3 by separate gas removal means.

As shown in FIGS. 1, 2 and 3, the water vapor and steam stream H, produced in the vaporization zone E, is withdrawn by a suction fan 22 into the feed end structure 4. The water vapor and steam stream H is drawn into the conduit 23 past a damper 24 and into a steam condenser 25 before being vented to the atmosphere.

The hydrocarbon gases and vapors stream I, produced in the vaporization zone E, is drawn by a suction fan 26 toward the product end structure 5. These gases and vapors are withdrawn through the conduit 27 into one or more dust extractors 28, to remove the fine particulates therefrom. A cooler 29 and condenser 30 are provided to condense a portion of the vapors into a liquid product stream, which can be pumped to a remote or adjacent processing facility. The non-condensable hydrocarbon gases are thereafter cooled before being conveyed to a processing facility.

A combustion gas stream J is withdrawn from the annular space A into the feed end structure 4 by a suction fan 31. The gases are drawn through a conduit 32 through a cyclone 33 and wet scrubber-type dust extractor 34 before being vented to the atmosphere through an exhaust stack (not shown). The scrubber-type extractor 34 is operative to remove the fine particulates carried with the gases. Preferably the water in the extractor 34 has a high content of calcium ions. The dissolved calcium sulphate oxidizes to form water-insoluble calcium sulphate. The sludge removed from the dust extractor 34 is passed through sludge thickener 35 and disposed of with the tailings solids.

To control the movement of the gases in the tubular members 2, 3, sealing means are provided, which means are not absolute seals but permit a net movement of gases in a manner to be hereinafter described. It is difficult to attain absolute seals when dealing with the rotating tubular members 2, 3 operating at high temperatures.

The feed end and product end structures 4, 5, as previously mentioned, provide end seals 35, 36 for the first and second ends B, C of the outer tubular member 3. These seals 35, 36 are constructed so as to permit a slight inward leakage of air into the annular space A. The pressure within the tubular members 2, 3 is maintained at slightly less than atmospheric pressure, or in other words, negative relative to atmospheric pressure. This negative pressure is drawn by the suction fan 31 removing the combustion gases. This pressure differential between the atmosphere and the annular space A prevents combustion gases from escaping into the atmosphere. The pressure differential is small, maintaining a pressure of about $-0.1''$ W.G. in the annular space A.

Most preferably, slight pressure differentials are maintained between the annular space A and zones D and E, to prevent hydrocarbon vapors from leaking into either the preheat zone D or combustion zone F. To that end, the pressure in the vaporization zone E, as drawn by the suction fan 26, is maintained less than the pressures in the preheat zone D and the annular space

A. The pressure in the vaporization zone E is typically kept at about $-0.2''$ W.G. The pressure in the preheat zone D is typically kept at about $-0.12''$ W.G. And, as previously stated, the pressure in the annular space A is typically kept at about $-0.1''$ W.G. Additionally, means 9 are provided in the inner tubular member 2 intermediate the preheat and vaporization zones D, E for restricting gas movement therebetween. Briefly, these means 9 comprise a solid circular partition wall 37 having perforations 38 around its periphery to permit the tar sand solids to be passed therethrough while restricting gas movement. By "restricting" is meant that the gas movement is less than would be the case if the gases were permitted to freely diffuse between the zones.

By maintaining these pressure differentials, the net movement of gases is such that a small amount of outside air is drawn into the annular space A, a small amount of the gases in the annular space A is drawn into the preheat zone D, and a small amount of gas from the preheat zone D is drawn into the vaporization zone E. In this manner, significant loss of the product hydrocarbon gases to the preheat zone D and annular space A is prevented, to thereby maximize recovery and minimize the possibility of creating explosive gaseous mixtures.

Other net results of this method of segregating the gases are that, with the elimination of absolute seals, the preheat zone D is open to accommodate whole oil sand feed, the heat-transfer zone G is open to accommodate lifting means for efficient heat transfer, and the vaporization zone E is open to achieve adequate mixing by gentle cascading of the hot recycle sands and the preheated solids.

It should be pointed out that the recycle means 10, to be discussed more fully hereinafter, cooperate with the hot oil sand solids being transferred therein (from the combustion zone F to the vaporization zone E) to prevent significant gas movement between these zones. Also, the means 12 for transferring coked solids from the vaporization zone E to the combustion zone F cooperate with said coked solids to prevent significant gas movement between these zones. These means however do not form absolute seals, thereby permitting the desired net movement of gases as discussed above.

If desired, a considerable portion of the steam and water vapor produced in the preheat zone D may be drawn through the vaporization zone E by controlling the suction drawn on these two zones. The water vapor may thereby be used as a stripping agent in the thermal cracking of the hydrocarbons in the vaporization zone.

As shown in FIG. 4, an emergency gas removal conduit 79 is provided at the second end of the outer tubular member 3 to remove gases from the processor 1 in the event of an emergency shut-down.

The Inner and Outer Tubular Members

The rotating apparatus of the present invention includes a horizontally disposed inner tubular member 2 having first and second ends and a horizontally disposed outer tubular member 3 having first and second ends. The tubular members 2, 3 may be constructed from fabricated or cast metal cylinders. The outer tubular member 3 is generally coextensive with the inner tubular member 2 and is radially spaced therefrom. The tubular members are rigidly connected together by suitable means 39 for concurrent rotation about their common long axes.

The outer tubular member 2 is provided with one or more riding rings 40 fixed around its outer circumference. The riding rings 40 rest on rollers 41. An electrical motor 42 or other suitable power source is used to impart rotary motion to the apparatus through a ring gear 43 affixed to the outer tubular member 3. The rate of rotation is variable to control the movement of the feed material being advanced through the apparatus.

To support the inner tubular member 3 within the outer tubular member 2, a series of radially extending braces 39 are bolted between them. The braces 39 are enclosed in insulative material, which in turn is surrounded with suitable abrasive resistive material (not shown). The insulation is included to isolate the braces from the high temperatures in the apparatus and to reduce the dimension changes caused by temperature fluctuations.

The outer tubular member 3 is provided with an outer lining 94 constructed of a refractory material with a coarse grog to minimize heat loss from the apparatus. Along the length of the combustion zone F, the outer surface of the inner tubular member 2 may be lined with a refractory material (not shown) to prevent the inner vaporization zone E from being over-heated. This lining also serves to protect the outer surface of the inner tubular member 2 from abrasive or oxidative damage.

Advancing means 6 are provided along the inner surfaces of the inner and outer tubular members 2, 3 to move the solids therealong as the members are rotated. Such advancing means 6, may be metal plates inclined relative to the long axes of the tubular members 2, 3. Counterclockwise rotation of the tubular members 2, 3 as viewed from the feed end causes advancement of the solids in the inner tubular member 2 from the first end toward the second end thereof and solids in the annular space A from the second end toward the first end thereof. The degree to which the advance plates 6 are inclined together with the number and spacing of the plates are varied to control the speed at which the solids are moved through the apparatus. Also provided in the preheat zone are keying elements 6a which comprise metal plates closely packed with the advance plates 6. The keying elements 6a promote lifting and mixing of the oil sand solids. The advance plates 6 and keying elements 6a are bolted to the wall 16 of the inner member 2 and, being of metal, aid in the heat transfer through the wall 16. At the entrances to the preheat, vaporization and combustion zones D, E, F, the advance plates 6 are arranged to move the solids quickly into the zone in question to prevent build-up of the solids. Further into these zones, the advance plates 6 are angled to cause slower movement of the solids. In the preheat zone D, the advance plates 6 are closely packed and inclined at a steep angle. Together with the keying elements 6a, the advance plates 6 provide a cascading action to the feed material as the tubular member 2, 3 are rotated, which action aids in reducing the particle size of the feed material.

In the vaporization zone, the combination of the advance plates 6 and mixing spikes 6b create a gentle mixing and cascading action to the oil sand solids.

Lifting means 17 are provided in the heat-transfer zone G to lift and drop hot sand solids onto the outer surface of the inner tubular member 2. These lifting means 17 comprise cup-faced lifters 44, as detailed in FIG. 7, bolted to the side wall 19 of the outer tubular member 3. These cup-faced lifters 44 are operative to

lift and drop the hot solids over the top of the rotating inner tubular member 2 as the tubular members rotate.

Similar lifting means of smaller lifting capacity may be used in the preheat and combustion zones D, F if desired.

The Feed End Structure

With reference to FIGS. 2 and 9, the feed end structure 4 is shown to include means 45 for feeding whole oil sand solids into the preheat zone D. The feeding means 45 includes a conveyor assembly 46 which drops the whole oil sand solids into an enclosed feed chute 47 opening into the first end of the inner tubular member 2.

A ring seal 48 is provided between the feed chute 47 and the inner tubular member 2 to form a gas seal therebetween. An air lock member 49 is provided to permit the oil sand solids to enter the inner tubular member 2 without significant gas movement. The ring seal 48 cooperates with the enclosed chute 47 and the air lock member 49 to prevent any significant quantities of external air from being drawn into the inner tubular member, thereby forming means for sealing the first end of the inner tube.

Oversize Solids Removal

Oversize feed material solids, which include rocks, large lumps of oil sand or other debris, are transferred from the inner tubular member 2 to the outer tubular member 3 at the second end 50 of the preheat zone D. To that end, curved metal bars 51 having one end affixed to the walls 16 of the inner tube 2 and the other end affixed to a bypass chute 52 are provided. The curved bars 51 are spaced from each other to form a screen through which the de-rocked feed material may pass as the inner tube 2 rotates. The oversize particles, larger than the spacing of the bars 51, roll along the bars into the bypass chute 52. The bypass chute 52 opens into the annular space A. A door 53 is provided on the bypass chute 52 which is spring-biased or cam operated to a normally closed position. On opening the door 53, the oversize solids are transferred directly into the annular space A for disposal. The door 53 minimizes the transfer of gases between the two tubular members 2, 3.

The Partition Wall

The means 9 for restricting gas movement between the preheat and vaporization zones D, E, as shown in FIGS. 4, 13 and 14, comprises a perforated wall member 37 extending across the inner tubular member between the two zones and positioned downstream of the oversize removal means. The wall member 37 comprises a solid circular plate 54 blocking the central portion of the inner tube 2. A plurality of curved tubular members 55 are affixed to the wall 16 of the inner member 2 through the plate 54. The tubular members provide openings 38 through the plate 54. The tubular members have open ended first and second ends, 56, 57, the first end 56 opening into the preheat zone D and the second end 57 opening into the vaporization zone E. A plurality of circular spaced bars 58 are provided over the openings 38. The bars 58 screen the oil sand material entering the tubular members 55 to prevent oversize material from blocking the openings or from being transferred into the vaporization zone D. The bars 58 are spaced in an L-shaped configuration over the first ends 56 of the tubular members 55. This configuration is shown clearly in FIGS. 12 and 13. The tubular members 55 are oriented so as to scoop the preheated oil sands

thereinto on rotation of the inner tubular member 2. On further rotation, the oil sand falls therethrough into the vaporization zone. The number and size of openings provided is determined by quantity of sand to be passed and the degree of gas control needed.

The ends of the tubular members 56, 57 are the only openings between the preheat and vaporization zones D, E. Since the tubular members 55 are at least partially full of tar sand solids while the processor 1 is rotated, the sands cooperate with the perforated wall 37 to restrict gas movement between the two zones D, E.

Preferably, a removable access door 54a is provided in the plate 54 to allow one access to the vaporization zone E for repairs or the like during a shut-down period.

Recycling Hot Oil Sand Solids From the Annular Space to the Vaporization Zone

The recycle means, as shown in FIGS. 4, 14 and 15 and generally indicated at 10, functions to divert a portion of the hot sand solids being advanced through the annular space A back into the vaporization zone E, where it is combined with the oil sand solids issuing from the preheat zone D. The recycle means 10 includes an annular housing 59 affixed to outer member 3 adjacent the entrance to the vaporization zone E. The annular housing 59 is divided into compartments 60 by dividing walls 61 extending between the walls of the housing 59 and the outer member 3. Recycle tubes 62 extend from each compartment 60 through the walls 19, 16 of the outer and inner members into the vaporization zone E. The recycle tubes 62 are tapered toward the inner member 2. Screened openings 63 are provided through the walls 19 of the outer member 3 into compartments 60.

As the tubular members 2, 3 are rotated, hot sand solids being advanced from the combustion zone F to the heat-exchange zone G pass over the screened openings 63 and fall into the compartments 60 for recycle. The screens 64 prevent large particles from being recycled. As the filled chambers 60 are rotated to an elevated position, the hot sand solids fall through the tapered tubes 62 into the vaporization zone E. The remaining hot sand solids are advanced to the heat-transfer zone G.

It will be understood that, since the hot sand solids passing between the combustion and heat-transfer zones F, G must pass over the screened openings 63, the compartments 60 must be preferentially filled before the excess solids can be advanced to the heat-transfer zone G.

As previously disclosed, the hot tar sand solids at least partially filling the compartments 60 and recycle tubes 62 cooperate with the recycle means 10 to prevent significant gas movement between the annular space A and the vaporization zone E.

To adjust the rate of the recycle flow, a removable plate 65 is bolted to each of the tubes 62 to form an outlet opening 66 between the recycle tube 62 and the inner tube 2. By adjusting either the size or location of the plates 65, the dimensions of the outlet openings 66 may be altered thereby adjusting the amount of material being recycled as required to achieve the desired processing result.

Preferably weir plates 59a are provided partially closing the entrance into the heat-transfer zone G. The plate 59a causes hot sand solids being advanced past the

recycle means 10 to accumulate over the screened openings 63 before falling into the heat-transfer zone O.

As shown in the drawings, an optional second recycle means (not shown) is provided to recycle hot sand solids from the heat-exchange zone O to the preheat zone D. The second recycle means are provided for use in the event that oil sand solids in the preheat zone D adhere to the inner surface 16 or advance elements 6 of the inner tube 2. The operation and construction of the second recycle means are similar to recycle means 10 described above. A number of the tubes 62 or compartments 60 are closed to recycle only a fraction of the amount of material being recycled by means 10. In most applications the second recycle means is not needed and all compartment openings 63 and recycle tube outlets 66 are closed.

Transferring Coked Solids From the Vaporization Zone to the Combustion Zone

Means 12 are provided at the second end C of the inner tubular means 2 for transferring hot coked solids from the vaporization zone E to the combustion zone F. These means are shown in detail in FIGS. 16 and 17. The second end C of the inner tubular member 2 is provided with spaced inner and outer radial end plates 68, 69 fixed to the walls 16 of said member 2 and sealed around the vapor removal conduit 27. A series of spaced baffles 70 are provided between the plates 68, 69 thereby forming compartments 71. As the inner member 2 rotates, coked solids from the vaporization zone E are fed into these compartments 71 through openings 72 provided near the periphery of the inner radial plate 68. Further rotation causes the solids to fall inwardly toward the central axis of the inner tubular member 2. The baffles 70 are inclined so as to direct the solids toward a central slot 73 located in the outer plate 69 around the vapor discharge conduit 27. The coked solids issuing from the slot 73 fall as a curtain through the space 74 between the second ends C of the tubular members 2,3 into the combustion zone F.

As the coked solids are being discharged through the slot 73, a moving solids seal is formed between the vaporization and combustion zones E, F to prevent significant gas movement between these zones. The circular slot 73 is further sealed during the remaining 360° of rotation by an adjustable seal plate 75. The seal plate 75 is spring mounted to the second end C of the outer tubular member 3 on adjustable rods 76 and sealed around the vapor removal conduit 27. The seal plate 75 is spaced from the circular slot opening 73 by an adjustable distance as set by the length of the rods 76. Spring mounting the plate 75 allows intermittent discharge of oversize material without permitting significant gas movement into the vaporization zone E.

End Seals of the Outer Tubular Member

The first end B of the outer tubular member 3 is sealed by a ring seal 35 between the wall 19 of the member 3 and the stationary feed end structure 4. As previously disclosed, this seal 35 permits a small amount of outside air to be leaked into the annular space A.

The second end C of the outer member 3 is sealed by the ring seal 36 between the stationary product end structure 5 and the wall 19 of the outer member 3. The stationary product end structure 5 is sealed to the vapor discharge conduit 27 by a rotary pipe seal 80.

The vapor discharge conduit 27 preferably comprises an outer stationary section 81 rigidly secured to the

rotary pipe seal 80 and a rotating inner section 82 affixed to and rotating with the end plates 68, 69 on the inner tubular member 2.

Introducing Oxygen-Containing Gas

With reference to FIGS. 4 and 18, means B are provided for introducing an oxygen-containing gas, such as air, into the combustion zone F. More particularly, a slotted air discharge plenum 83 is provided in the space 74 between the second ends C of the tubular members 2,3. The plenum 83 is connected through a conduit 84 to a fan 85 which forces heated air through the plenum 83. The air is heated in heat exchangers 77 which recover heat from the hydrocarbon vapours withdrawn from the vaporization zone E. A direct fire burner 18 supplies additional heated air to the combustion zone F to supplement the heating provided by combustion. The plenum 83 is curved in the manner shown in the drawings to allow maximum contact of the heated air with the curtain of hot coked solids issuing from the inner tubular member 2. At the base of the plenum 83 a horizontal plenum nozzle 86 extends a small distance into the annular space A. This nozzle 86 supplies a high velocity stream of air along the annular space A to ensure that combustion continues along the extent of the combustion zone F.

Sand Solids Removal

The sand solids are removed from the annular space A at the first end B of the outer tubular member 3 by means generally indicated at 21 in FIGS. 2 and 4. The sand solids are dropped onto an enclosed conveyor belt 91 external of the outer member 3, where they are cooled and dampened with water. The cooled sands are conveyed through an air lock 87 to a disposal site. The steam resulting from cooling the hot sands, shown as stream K in FIG. 3, is combined with the steam and water vapor stream H from the preheat zone D and cooled in the previously disclosed manner.

Operation

To process oil sand feed material, the temperature in the apparatus is initially raised to about 1000° F. by introducing hot air at a temperature of about 1100° F. through the burner 18. The apparatus 1 is then purged with steam to remove oxygen therefrom. With the tubular members 2,3 rotating, whole oil sands solids, which may have been prescreened to remove large boulders, are conveyed into the preheat zone D through the feed chute 47. The high angle of attack of the advance plates 6 move the feed material quickly into the preheat zone D. In the preheat zone D, the feed material is heated, dehydrated and ablated as it is advanced therethrough by the inclined advance plates 6.

The heat is provided by heat transferred through the wall 16 of the inner tubular member 2 from the hot sand solids being dropped thereon in the surrounding annular space A. The oil sands are preferably preheated to a temperature of about 450° F. This heating causes a substantial reduction of the bitumen viscosity. As the tubular members 2,3 rotate, the feed material is repeatedly raised and dropped to create a cascading effect. The advance plates 6 and keying elements 6a are closely spaced to aid in this lifting action. This preheating and cascading of the whole oil sand in the preheat zone D causes lumps of oil sand to be ground and reduced in particle size. This combined action also conditions the feed material to release oversize debris such as rocks

from the lumps of oil sand. Oversize solids can thus be subsequently removed without losing a large quantity of oil sands.

The preheating step also vaporizes essentially all of the water associated with the oil sand feed material. The temperature in the preheat zone is maintained below about 700° F., to prevent any substantial amount of vaporization of the bitumen. The temperature in the preheat zone D is controlled by the residence time of the feed material therein. Residence time varies with the speed of rotation of the tubular members 2,3 and the size and spacing of the advance plates 6 in the preheat zone D. Alternately the degree of lifting and dropping of the hot sand solids onto the outer surface 16 of the inner member can be varied. The water vapor and steam are withdrawn from the preheat zone D by the suction fan 22 and conduit 23 to the steam condenser 25.

By lowering the viscosity of the bitumen in the oil sand solids, the feed material is much less cohesive and more amenable to flow and to screening of oversize solids.

The steam and water vapor produced in the preheat zone D creates a slightly greater pressure in the preheat zone D than in the vaporization zone E. This provides an inert sealing atmosphere which, together with the partition wall 9, is operative to prevent significant movement of the gases between these two zones D, E.

It will be appreciated that if the amount of water present in the whole oil sand feed material is not sufficient to generate this steam barrier, water may be injected directly into the preheat zone D. Alternately the damper 24 on the steam removal means 7 can be closed so that the steam and water vapor are drawn into the vaporization zone E and removed with the hydrocarbon vapors.

At the second end 50 of the preheat zone D, oversize solids, including rocks and other debris or large lumps of oil sand solids, are separated and removed into the annular space A by the oversize removal means 8. Solids larger than the spacing of the curved bars 51 roll or slide along the bars 51 into the discharge chute 52 and are ejected into the annular space A. In this way, damage to the downstream equipment in the vaporization and combustion zones E, F is prevented.

Downstream of the oversize removal means 8, the de-rocked and preheated oil sand solids are passed through the openings 38 around the periphery of the partition wall 37 into the curved tubular members 55. Rotation of the inner tubular member 2 drops the solids into the vaporization zone E. Since the tubular members 55 are at least partially filled with the solids as the apparatus rotates, the solids cooperate with the wall 37 to restrict gas movement between the zones D, E.

In the vaporization zone E the preheated solids are further heated by introducing hot recycled solids through the recycle means 10 at the first end 88 of this zone. These hot solids recycled from the combustion zone F are typically at a temperature of about 1100°-1300° F. Rotation of the tubular members 2, 3 creates a gentle mixing or cascading action in the vaporization zone E to bring the overall temperature of the solids to about 900°-1000° F. Advance plates 6 and mixing spikes 66, positioned along the inner surface 16 of the inner tubular member 2 defining the vaporization zone E, advance and mix the solids toward the second end C of the inner member 2. The quantity of hot solids recycled is varied by adjusting the size of the outlet openings 64 provided by the recycle means 10. By vary-

ing the amount of solids recycled, the temperature in the zone can be controlled to optimize the degree of vaporization. It is desirable to try to reduce turbulence of the solids in the vaporization zone E to a minimum and thereby reduce the amount of fine particulates in the atmosphere.

The heat added in the vaporization zone E to the oil sand is sufficient to cause thermal cracking and vaporization of a portion of the bitumen and to produce a gaseous hydrocarbon product stream. The product stream is withdrawn from the vaporization zone E through the vapor discharge conduit 27 by the suction fan 26. The vapors are cleaned in one or more dust extractors 28 to remove the fine particulates entrapped therein. The vapors are then cooled and condensed to produce a liquid product. The non-condensable hydrocarbon vapors are further cooled and condensed to produce a gaseous hydrocarbon product.

After vaporizing at least a portion of the bitumen, a coke residue is left in association with the solid mineral particles. The coke residue and mineral solids are collectively referred to as coked solids.

At the second end 89 of the vaporization zone E, the coked solids are transferred into the combustion zone F. As described previously, the means 12 for transferring the coked solids between these zones drops the solids in a curtain-like pattern. The curtain of falling particles is struck by a stream of high velocity hot air emitted from the plenum 83. The hot air supports combustion of at least a portion of the coke residue on the coked solids. By this combustion and supplemental heating with the burner 14, the overall temperature of the coked solids may be raised to about 1100°-1300° F.

The combustion-heated solids are advanced through the annular space A toward the first end B of the outer tubular member 3 by the advance plates 6. A high velocity hot air stream is projected along the annular space A to support combustion therealong. In addition, the combustion-heated solids are preferably lifted and dropped in the combustion zone F by lift elements 90. As shown in FIG. 7, the lift elements 90 are flat-type lifters. This lifting and dropping action provides maximum contact between the air and solids to maximize combustion.

The combustion gases and combustion-heated solids give up a portion of their heat, by convection and conduction, to the inner tubular member 2.

While it is believed that the majority of the combustion takes place in the annular space A, some combustion will also take place in the space 74 between the second ends C of the tubular members 2,3. Thus the term "annular space" as used in the claims should be taken to refer both to the annular space between the walls 16, 19 of the tubular members 2,3 and the space 74 between their second ends C. It is conceivable that the outer tubular member 3 could be extended to enlarge the space 74 if a larger combustion zone is desired.

A portion of the combustion-heated solids are recycled back from the annular space A into the vaporization zone E, to provide the hot recycle solids. As the tubular members 2,3 rotate, the combustion-heated solids are advanced over and fall into the screened openings 63 to the compartments 60. Further rotation of the tubular members 2,3 drops the hot recycle solids through the recycle tubes 62 into the vaporization zone E. The solids at least partially filling the recycle tubes 62 form a moving solids seal between the combustion and vaporization zones E, F to prevent significant gas

movement therebetween. Also, since the combustion-heated solids must pass over the screened openings 63 and over the weir plate 59a as they are advanced through the annular space A, the recycle means 10 are preferentially filled before the hot solids are advanced for disposal. This preferential filling of the recycle means 10 ensures a moving solids seal and a supply of hot recycle solids to the vaporization zone E even when the rate of feed material input is temporarily reduced.

That portion of the combustion-heated solids which is not recycled is advanced through the heat-transfer zone G. In the heat-transfer zone G these hot solids are repeatedly lifted and dropped onto the section 15 of the wall 16 of the inner tubular member 2 which defines the preheat zone E. In this way, waste heat from the hot solids is efficiently transferred to the feed material in the preheat zone E. By achieving a sliding solid-solid contact between the wall 16 of the inner member 2 and the hot solids, a desirable amount of heat is transferred. The lifting and dropping of the hot solids is achieved by the cup-faced lifters 44 affixed to the inner surface of the outer tubular member 3. This type of lifter has a large lifting capacity and actually lifts and drops the solids over the top of the rotating inner member 2 to contact the surface area of the inner tubular member 2.

The rate of solids movement through the heat-transfer zone G is relatively slow, as provided by the large spacing and small size of the advance plates 6 in this area. The slow rate of advance allows a maximum amount of heat to be recovered from the hot solids.

A suction fan 26 at the first end C of the outer tubular member 3 withdraws the combustion gases from the annular space A. The combustion gases are passed through a gas cleaning cyclone and wet extractor before being vented to an exhaust stack (not shown).

Solids from the heat transfer zone G, which include oversize solids and combustion-heated solids, are removed by dropping the solids from the first end B of the outer tubular member 3 onto the enclosed conveyor belt 91. The solids are cooled and dampened on the belt 91 by spraying them with a cooling fluid such as water. Steam produced in cooling the solids is directed through the conduit 82, past damper 93 and combined and removed with the steam from the preheat zone D. The dampened solids are conveyed through the air lock 87 to a disposal site. Alternately the solids may be cooled and dampened in the annular space A just prior to being removed from the processor 1. In some cases it may be desirable to cool and dampen the solids in both the annular space and exterior of the processor as is shown in FIG. 4. The cooling fluid may include thickened sludge withdrawn from the wet dust extractor as shown in FIG. 2.

As described above the gases produced in each of the preheat zone D, vaporization zone E and annular space A are substantially segregated from one another and removed from the apparatus 1 by separate gas removal means 7, 11 and 20 respectively. Preferably the pressures in each of these zones is controlled to maintain a pressure in the vaporization zone E which is less than the pressure in the preheat zone D and annular space A. Most preferably the pressures in the vaporization zone E, preheat zone D and annular space A are maintained at levels which ascend respectively. These pressures are preferably negative with respect to the atmospheric pressure outside the apparatus. This pressure control, as disclosed previously, is operative to maximize the removal of hydrocarbon vapors for recovery while mini-

mizing movement of hydrocarbon vapors into another zone and movement of combustion gases out of the apparatus.

A pilot plant unit processor was operated using Athabasca oil sand from Alberta. The processor was sized to handle 5 tons of feed material per hour. The processor had an inner tubular member having dimensions of 5.5' in diameter by 20' in length. The outer tubular member was 9' in diameter by 22' in length. Both the preheat and heat transfer zones were 12' in length while the vaporization and combustion zones were each 8' in length. The processor was rotated at about 3 to 6 R.P.M. most preferably at 4 R.P.M.

Retention times and temperatures for the various zones are shown in Table 1. A typical product analysis from a particular feed material is shown in Table 2.

TABLE 1

Zone	Retention Time	Temperature
Preheat Zone	4 min.	ambient to 450° F.
Vaporization Zone	2 min.	450° F.-950° F.
Combustion Zone	1.5 min.	950° F.-1080° F.
Heat-Transfer Zone	5 min.	1080° F.-500° F.
Final Cooling	<1 min.	500° F.-180° F.
Vapor Exit Temperature		970° F.
Combustion Gas Exit Temperature		520° F.

TABLE 2

(For Vapor Zone Temperature 900-1050° F.)

Feed Analysis	Product Analysis
Oil 9%, 7° API	Liquid Yield 60-72% of feed
Water 7.5%	API gravity 13° API
Host Sand and Clay 83.5%	Sediment and Water <2%
Sulphur 4.3%	Sulphur 3.7%
	Viscosity @ 20° C. 300 c.s.
	Coke Yield 18-30% of feed
	Crack Gas Yield (C ₄ -) 7-13% of feed

Due to processing considerations in the test unit auxiliary heating was needed to provide a substantial amount of the heat requirements. Approximately 3 gallons of fuel oil per ton of feed were burned in auxiliary burners.

As previously mentioned, the invention has only been practiced on oil sands. However, it is anticipated that other materials comprising hot solids associated with hydrocarbons (such as oil shale) may also be processed by the invention.

It will be realized that oil shales and certain oil sands do not contain connate water. For this reason it may be necessary to inject water or an inert gas into the preheat zone D to maintain an inert atmosphere therein. Such materials may not contain oversize solids, in which case the oversize removal means 8 may be omitted.

While the present invention has been disclosed in connection with the preferred embodiment thereof, it should be understood that there may be other embodiments which fall within the spirit and scope of the present invention as defined in the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for recovering hydrocarbons from whole oil sand containing sand and clay solids in discrete and lump forms, water, bitumen and oversize solids using a processor which comprises rotatable inner and outer spaced tubular members, having first and

second ends, said outer member being sealed at its ends and said inner member being sealed at its first end, said inner member providing an open pre-heat zone at its first end and an open vaporization zone at its second end, said members combining to form an open substantially annular space having a combustion zone at its second end and a heat transfer zone at its first end,

said method comprising:

advancing the whole oil sand through the preheat zone and cascading it therein while heating it by heat transfer through the wall of the inner member to vaporize substantially all the water, without significant vaporization of hydrocarbons, and to effect size reduction of oil sand lumps;

separating oversize solids at the second end of the preheat zone and removing them into the annular space;

advancing the remaining preheated oil sand through the vaporization zone while further heating it by mixing it with hot recycled solids to vaporize and crack hydrocarbons and produce coked solids;

restricting gas movement between the preheat and vaporization zones;

withdrawing at least the greatest part of the water vapor and the greatest part of the hydrocarbon vapors separately from the processor;

transferring coked solids from the vaporization zone into the combustion zone while preventing significant gas movement between these zones in the course of the transfer;

burning at least part of the coke in the combustion zone to heat the solids;

withdrawing at least the greatest part of the combustion gases produced from the combustion zone;

advancing combustion-heated solids from the combustion zone to the heat-transfer zone;

recycling part of the combustion-heated solids into the vaporization zone to heat the preheated oil sand while preventing significant gas movement between the annular space and the vaporization zone in the course of the transfer;

advancing combustion-heated solids through the heat-transfer zone and lifting said solids and dropping them onto the wall of that portion of the inner member forming the preheat zone to transfer heat through said wall; and

removing combustion-heated and oversize solids from the processor as they complete their travel through the heat transfer zone.

2. The method as set forth in claim 1 comprising: maintaining the pressure in the vaporization zone at a level less than that in either the preheat zone or the annular space.

3. The method as set forth in claim 1 comprising:

maintaining the pressures in the vaporization zone, preheat zone, and annular space at levels which ascend respectively.

4. A method for recovering hydrocarbons from host solids containing hydrocarbons, using a processor which comprises rotatable inner and outer spaced tubular members, having first and second ends, said outer member being sealed at its ends and said inner member being sealed at its first end, said inner member providing an open preheat zone at its first end and an open vaporization zone at its second end, said members combining to form an open substantially annular space having a combustion zone at its second end and a heat transfer zone at its first end,

said method comprising:

advancing the host solids through the preheat zone and cascading it therein while heating it by heat transfer through the wall of the inner member to vaporize substantially all the water, without significant vaporization of hydrocarbons;

advancing the preheated host solids through the vaporization zone while further heating it by mixing it with hot recycled solids to vaporize and crack hydrocarbons and produce coked solids;

restricting gas movement between the preheat and vaporization zones with an apertured baffle;

withdrawing at least the greatest part of the water vapor and the greatest part of the hydrocarbon vapor separately from the processor;

transferring coked solids from the vaporization zone into the combustion zone while preventing significant gas movement between these zones in the course of the transfer;

burning at least part of the coke on the coked solids in the combustion zone to heat the solids and withdrawing combustion gases produced from the processor;

advancing combustion-heated solids from the combustion zone to the heat-transfer zone;

recycling part of the combustion-heated solids into the vaporization zone to heat the preheated host solids while preventing significant gas movement between the annular space and the vaporization zone in the course of the transfer;

advancing combustion-heated solids through the heat-transfer zone and lifting said solids and dropping them onto the wall of that portion of the inner member forming the preheat zone to transfer heat through said wall;

removing combustion-heated solids from the processor as they complete their travel through the heat transfer zone; and

maintaining the gaseous atmospheres in the preheat and vaporization zones and the annular space substantially segregated one from another by said withdrawing and restricting steps.

the particle size of the lumps of oil sand material and releases rocks and other debris from these lumps for their subsequent removal. The water vapor and steam from the preheat zone are withdrawn by first gas removal means 7.

Also provided in the preheat zone D is means 8 for separating and transferring oversize solids from the preheated and ablated feed material. This oversize material, which includes rocks, lumps of oil sand material relative to particle size reduction and other large debris, is dropped into the annular space A for disposal.

Means 9 are provided between the preheat and vaporization zones D, E for restricting gas movement between these zones while permitting the remaining preheated oil sands to be advanced therethrough.

In the vaporization zone E, the remaining preheated solids are mixed with hot recycle solids recycled from the combustion zone F through recycle means 10. The temperature of the preheated solids is thereby rapidly raised to a level sufficient to thermally crack and vaporize a portion of the bitumen component. The hydrocarbon vapors produced are removed as a product by second gas removal means 11 provided at the second end of the inner tubular member 2.

As a result of thermally cracking and vaporizing hydrocarbons in the oil sand material, coked solids particles are produced. These coked solids comprise a coke residue in association with the remaining sand. At the second end of the inner tubular member 2, means 12 are provided for transferring the coked solids from the vaporization zone E into the combustion zone F. These means 12 cooperate with the coked solids to prevent any significant gas movement between these zones E, F.

Means 13 are provided for introducing an oxygen-containing gas, such as air, into the combustion zone F for burning at least part of the coke on the coked solids to produce hot sand solids. This combustion, together with any supplemental heat which may be required, raises the temperature of the sand solids to a level sufficient to cause vaporization in the vaporization zone when such hot solids are recycled. Supplemental heat can be provided by introducing heated air from a burner 14 into the annular space A.

As the combustion-heated solids are advanced toward the feed end structure 4, a portion of such hot solids is recycled to the vaporization zone E as described previously. The remaining combustion-heated solids are advanced back through the heat-transfer zone G.

In the heat-transfer zone G, the hot combustion-heated solids are lifted and dropped onto that section 15 of the wall 16 of the inner tubular member 2, which section forms the preheat zone D. For this purpose, lifting means 17 are provided along at least part of the inner surface of that section 18 of the wall 19 of the outer tubular member 3, which section forms the heat-transfer zone G. Waste heat which would otherwise be lost is thus recovered and transferred to the solids in the preheat zone D.

Combustion produced gases are withdrawn from the annular space A by gas removal means 20 at the first end of the outer tubular member 3.

The sand solids completing travel through the heat transfer zone G are removed from the annular space A by the removal means indicated at 21. The hot sands are thereafter cooled and conveyed to a deposit area.

Segregating and Removing the Gases Produced

The gases and vapors produced as abovedescribed are of three types, namely, the water vapor produced in the preheat zone D, the hydrocarbon gases and vapors produced in the vaporization zone E, and the combustion gases produced in the combustion zone F. For purposes of safety and economics of recovery, these gaseous atmospheres are preferably substantially segregated from each other and withdrawn from the tubular members 2, 3 by separate gas removal means.

As shown in FIGS. 1, 2 and 3, the water vapor and steam stream H, produced in the vaporization zone E, is withdrawn by a suction fan 22 into the feed end structure 4. The water vapor and steam stream H is drawn into the conduit 23 past a damper 24 and into a steam condensor 25 before being vented to the atmosphere.

The hydrocarbon gases and vapors stream I, produced in the vaporization zone E, is drawn by a suction fan 26 toward the product end structure 5. These gases and vapors are withdrawn through the conduit 27 into one or more dust extractors 28, to remove the fine particulates therefrom. A cooler 29 and condensor 30 are provided to condense a portion of the vapors into a liquid product stream, which can be pumped to a remote or adjacent processing facility. The non-condensable hydrocarbon vapors are cooled and further cooled before being conveyed to a processing facility.

A combustion gas stream J is withdrawn from the annular space A into the feed end structure 4 by a suction fan 31. The gases are drawn through a conduit 32 through a cyclone 33 and wet scrubber-type dust extractor 34 before being vented to the atmosphere through an exhaust stack (not shown). The scrubber-type extractor 34 is operative to remove the fine particulates carried with the gases. Preferably the water in the extractor 34 has a high content of calcium ions. The dissolved calcium sulphate oxidizes to form water-insoluble calcium sulphate. The sludge removed from the dust extractor 34 is passed through sludge thickener 35 and disposed of with the tailings solids.

To control the movement of the gases in the tubular members 2,3, sealing means are provided, which means are not absolute seals but permit a net movement of gases in a manner to be hereinafter described. It is difficult to attain absolute seals when dealing with the rotating tubular members 2,3 operating at high temperatures.

The feed end and product end structures 4,5, as previously mentioned, provide end seals 35, 36 for the first and second ends B,C of the outer tubular member 3. These seals 35, 36 are constructed so as to permit a slight inward leakage of air into the annular space A. The pressure within the tubular members 2,3 is maintained at slightly less than atmospheric pressure, or in other words, negative relative to atmospheric pressure. This negative pressure is drawn by the suction fan 31 removing the combustion gases. This pressure differential between the atmosphere and the annular space A prevents combustion gases from escaping into the atmosphere. The pressure differential is small, maintaining a pressure of about $-0.1''$ W.G. in the annular space A.

Most preferably, slight pressure differentials are maintained between the annular space A and zones D and E, to prevent hydrocarbon vapors from leaking into either the preheat zone D or combustion zone F. To that end, the pressure in the vaporization zone E, as drawn by the suction fan 26, is maintained less than the pressures in the preheat zone D and the annular space

A. The pressure in the vaporization zone E is typically kept at about $-0.2''$ W.G. The pressure in the preheat zone D is typically kept at about $-0.12''$ W.G. And, as previously stated, the pressure in the annular space A is typically kept at about $-0.1''$ W.G. Additionally, means 9 are provided in the inner tubular member 2 intermediate the preheat and vaporization zones D, E for restricting gas movement therebetween. Briefly, these means 9 comprise a solid circular partition wall 37 having perforations 38 around its periphery to permit the tar sand solids to be passed therethrough while restricting gas movement. By "restricting" is meant that the gas movement is less than would be the case if the gases were permitted to freely diffuse between the zones.

By maintaining these pressure differentials, the net movement of gases is such that a small amount of outside air is drawn into the annular space A, a small amount of the gases in the annular space A is drawn into the preheat zone D, and a small amount of gas from the preheat zone D is drawn into the vaporization zone E. In this manner, significant loss of the product hydrocarbon gases to the preheat zone D and annular space A is prevented, to thereby maximize recovery and minimize the possibility of creating explosive gaseous mixtures.

Other net results of this method of segregating the gases are that, with the elimination of absolute seals, the preheat zone D is open to accommodate whole oil sand feed, the heat-transfer zone G is open to accommodate lifting means for efficient heat transfer, and the vaporization zone E is open to achieve adequate mixing by gentle cascading of the hot recycle sands and the preheated solids.

It should be pointed out that the recycle means 10, to be discussed more fully hereinafter, cooperate with the hot oil sand solids being transferred therein (from the combustion zone F to the vaporization zone E) to prevent significant gas movement between these zones. Also, the means 12 for transferring coked solids from the vaporization zone E to the combustion zone F cooperate with said coked solids to prevent significant gas movement between these zones. These means however do not form absolute seals, thereby permitting the desired net movement of gases as discussed above.

If desired, a considerable portion of the steam and water vapor produced in the preheat zone D may be drawn through the vaporization zone E by controlling the suction drawn on these two zones. The water vapor may thereby be used as a stripping agent in the thermal cracking of the hydrocarbons in the vaporization zone.

As shown in FIG. 4, an emergency gas removal conduit 79 is provided at the second end of the outer tubular member 3 to remove gases from the processor 1 in the event of an emergency shut-down.

The Inner and Outer Tubular Members

The rotating apparatus of the present invention includes a horizontally disposed inner tubular member 2 having first and second ends and a horizontally disposed outer tubular member 3 having first and second ends. The tubular members 2, 3 may be constructed from fabricated or cast metal cylinders. The outer tubular member 3 is generally coextensive with the inner tubular member 2 and is radially spaced therefrom. The tubular members are rigidly connected together by suitable means 39 for concurrent rotation about their common long axes.

The outer tubular member 2 is provided with one or more riding rings 40 fixed around its outer circumference. The riding rings 40 rest on rollers 41. An electrical motor 42 or other suitable power source is used to impart rotary motion to the apparatus through a ring gear 43 affixed to the outer tubular member 3. The rate of rotation is variable to control the movement of the feed material being advanced through the apparatus.

To support the inner tubular member 3 within the outer tubular member 2, a series of radially extending braces 39 are bolted between them. The braces 39 are enclosed in insulative material, which in turn is surrounded with suitable abrasive resistive material (not shown). The insulation is included to isolate the braces from the high temperatures in the apparatus and to reduce the dimension changes caused by temperature fluctuations.

The outer tubular member 3 is provided with an outer lining 94 constructed of a refractory material with a coarse grog to minimize heat loss from the apparatus. Along the length of the combustion zone F, the outer surface of the inner tubular member 2 may be lined with a refractory material (not shown) to prevent the inner vaporization zone E from being over-heated. This lining also serves to protect the outer surface of the inner tubular member 2 from abrasive or oxidative damage.

Advancing means 6 are provided along the inner surfaces of the inner and outer tubular members 2, 3 to move the solids therealong as the members are rotated. Such advancing means 6, may be metal plates inclined relative to the long axes of the tubular members 2, 3. Counterclockwise rotation of the tubular members 2, 3 as viewed from the feed end causes advancement of the solids in the inner tubular member 2 from the first end toward the second end thereof and solids in the annular space A from the second end toward the first end thereof. The degree to which the advance plates 6 are inclined together with the number and spacing of the plates are varied to control the speed at which the solids are moved through the apparatus. Also provided in the preheat zone are keying elements 6a which comprise metal plates closely packed with the advance plates 6. The keying elements 6a promote lifting and mixing of the oil sand solids. The advance plates 6 and keying elements 6a are bolted to the wall 16 of the inner member 2 and, being of metal, aid in the heat transfer through the wall 16. At the entrances to the preheat, vaporization and combustion zones D, E, F, the advance plates 6 are arranged to move the solids quickly into the zone in question to prevent build-up of the solids. Further into these zones, the advance plates 6 are angled to cause slower movement of the solids. In the preheat zone D, the advance plates 6 are closely packed and inclined at a steep angle. Together with the keying elements 6a, the advance plates 6 provide a cascading action to the feed material as the tubular member 2, 3 are rotated, which action aids in reducing the particle size of the feed material.

In the vaporization zone, the combination of the advance plates 6 and mixing spikes 6b create a gentle mixing and cascading action to the oil sand solids.

Lifting means 17 are provided in the heat-transfer zone G to lift and drop hot sand solids onto the outer surface of the inner tubular member 2. These lifting means 17 comprise cup-faced lifters 44, as detailed in FIG. 7, bolted to the side wall 19 of the outer tubular member 3. These cup-faced lifters 44 are operative to

lift and drop the hot solids over the top of the rotating inner tubular member 2 as the tubular members rotate.

Similar lifting means of smaller lifting capacity may be used in the preheat and combustion zones D, F if desired.

The Feed End Structure

With reference to FIGS. 2 and 9, the feed end structure 4 is shown to include means 45 for feeding whole oil sand solids into the preheat zone D. The feeding means 45 includes a conveyor assembly 46 which drops the whole oil sand solids into an enclosed feed chute 47 opening into the first end of the inner tubular member 2.

A ring seal 48 is provided between the feed chute 47 and the inner tubular member 2 to form a gas seal therebetween. An air lock member 49 is provided to permit the oil sand solids to enter the inner tubular member 2 without significant gas movement. The ring seal 48 cooperates with the enclosed chute 47 and the air lock member 49 to prevent any significant quantities of external air from being drawn into the inner tubular member, thereby forming means for sealing the first end of the inner tube.

Oversize Solids Removal

Oversize feed material solids, which include rocks, large lumps of oil sand or other debris, are transferred from the inner tubular member 2 to the outer tubular member 3 at the second end 50 of the preheat zone D. To that end, curved metal bars 51 having one end affixed to the walls 16 of the inner tube 2 and the other end affixed to a bypass chute 52 are provided. The curved bars 51 are spaced from each other to form a screen through which the de-rocked feed material may pass as the inner tube 2 rotates. The oversize particles, larger than the spacing of the bars 51, roll along the bars into the bypass chute 52. The bypass chute 52 opens into the annular space A. A door 53 is provided on the bypass chute 52 which is spring-biased or cam operated to a normally closed position. On opening the door 53, the oversize solids are transferred directly into the annular space A for disposal. The door 53 minimizes the transfer of gases between the two tubular members 2, 3.

The Partition Wall

The means 9 for restricting gas movement between the preheat and vaporization zones D, E, is shown in FIGS. 4, 13 and 14, comprises a perforated wall member 37 extending across the inner tubular member between the two zones and positioned downstream of the oversize removal means. The wall member 37 comprises a solid circular plate 54 blocking the central portion of the inner tube 2. A plurality of curved tubular members 55 are affixed to the wall 16 of the inner member 2 through the plate 54. The tubular members provide openings 38 through the plate 54. The tubular members have open ended first and second ends, 56, 57, the first end 56 opening into the preheat zone D and the second end 57 opening into the vaporization zone E. A plurality of circular spaced bars 58 are provided over the openings 38. The bars 58 screen the oil sand material entering the tubular members 55 to prevent oversize material from blocking the openings or from being transferred into the vaporization zone D. The bars 58 are spaced in an L-shaped configuration over the first ends 56 of the tubular members 55. This configuration is shown clearly in FIGS. 12 and 13. The tubular members 55 are oriented so as to scoop the preheated oil sands

thereinto on rotation of the inner tubular member 2. On further rotation, the oil sand falls therethrough into the vaporization zone. The number and size of openings provided is determined by quantity of sand to be passed and the degree of gas control needed.

The ends of the tubular members 56, 57 are the only openings between the preheat and vaporization zones D, E. Since the tubular members 55 are at least partially full of tar sand solids while the processor 1 is rotated, the sands cooperate with the perforated wall 37 to restrict gas movement between the two zones D, E.

Preferably, a removable access door 54a is provided in the plate 54 to allow one access to the vaporization zone E for repairs or the like during a shut-down period.

Recycling Hot Oil Sand Solids From the Annular Space to the Vaporization Zone

The recycle means, as shown in FIGS. 4, 14 and 15 and generally indicated at 10, functions to divert a portion of the hot sand solids being advanced through the annular space A back into the vaporization zone E, where it is combined with the oil sand solids issuing from the preheat zone D. The recycle means 10 includes an annular housing 59 affixed to outer member 3 adjacent the entrance to the vaporization zone E. The annular housing 59 is divided into compartments 60 by dividing walls 61 extending between the walls of the housing 59 and the outer member 3. Recycle tubes 62 extend from each compartment 60 through the walls 19, 16 of the outer and inner members into the vaporization zone E. The recycle tubes 62 are tapered toward the inner member 2. Screened openings 63 are provided through the walls 19 of the outer member 3 into compartments 60.

As the tubular members 2, 3 are rotated, hot sand solids being advanced from the combustion zone F to the heat-exchange zone G pass over the screened openings 63 and fall into the compartments 60 for recycle. The screens 64 prevent large particles from being recycled. As the filled chambers 60 are rotated to an elevated position, the hot sand solids fall through the tapered tubes 62 into the vaporization zone E. The remaining hot sand solids are advanced to the heat-transfer zone G.

It will be understood that, since the hot sand solids passing between the combustion and heat-transfer zones F, G must pass over the screened openings 63, the compartments 60 must be preferentially filled before the excess solids can be advanced to the heat-transfer zone G.

As previously disclosed, the hot tar sand solids at least partially filling the compartments 60 and recycle tubes 62 cooperate with the recycle means 10 to prevent significant gas movement between the annular space A and the vaporization zone E.

To adjust the rate of the recycle flow, a removable plate 65 is bolted to each of the tubes 62 to form an outlet opening 66 between the recycle tube 62 and the inner tube 2. By adjusting either the size or location of the plates 65, the dimensions of the outlet openings 66 may be altered thereby adjusting the amount of material being recycled as required to achieve the desired processing result.

Preferably weir plates 59a are provided partially closing the entrance into the heat-transfer zone G. The plate 59a causes hot sand solids being advanced past the

recycle means 10 to accumulate over the screened openings 63 before falling into the heat-transfer zone O.

As shown in the drawings, an optional second recycle means (not shown) is provided to recycle hot sand solids from the heat-exchange zone O to the preheat zone D. The second recycle means are provided for use in the event that oil sand solids in the preheat zone D adhere to the inner surface 16 or advance elements 6 of the inner tube 2. The operation and construction of the second recycle means are similar to recycle means 10 described above. A number of the tubes 62 or compartments 60 are closed to recycle only a fraction of the amount of material being recycled by means 10. In most applications the second recycle means is not needed and all compartment openings 63 and recycle tube outlets 66 are closed.

Transferring Coked Solids From the Vaporization Zone to the Combustion Zone

Means 12 are provided at the second end C of the inner tubular means 2 for transferring hot coked solids from the vaporization zone E to the combustion zone F. These means are shown in detail in FIGS. 16 and 17. The second end C of the inner tubular member 2 is provided with spaced inner and outer radial end plates 68, 69 fixed to the walls 16 of said member 2 and sealed around the vapor removal conduit 27. A series of spaced baffles 70 are provided between the plates 68, 69 thereby forming compartments 71. As the inner member 2 rotates, coked solids from the vaporization zone E are fed into these compartments 71 through openings 72 provided near the periphery of the inner radial plate 68. Further rotation causes the solids to fall inwardly toward the central axis of the inner tubular member 2. The baffles 70 are inclined so as to direct the solids toward a central slot 73 located in the outer plate 69 around the vapor discharge conduit 27. The coked solids issuing from the slot 73 fall as a curtain through the space 74 between the second ends C of the tubular members 2,3 into the combustion zone F.

As the coked solids are being discharged through the slot 73, a moving solids seal is formed between the vaporization and combustion zones E, F to prevent significant gas movement between these zones. The circular slot 73 is further sealed during the remaining 360° of rotation by an adjustable seal plate 75. The seal plate 75 is spring mounted to the second end C of the outer tubular member 3 on adjustable rods 76 and sealed around the vapor removal conduit 27. The seal plate 75 is spaced from the circular slot opening 73 by an adjustable distance as set by the length of the rods 76. Spring mounting the plate 75 allows intermittent discharge of oversize material without permitting significant gas movement into the vaporization zone E.

End Seals of the Outer Tubular Member

The first end B of the outer tubular member 3 is sealed by a ring seal 35 between the wall 19 of the member 3 and the stationary feed end structure 4. As previously disclosed, this seal 35 permits a small amount of outside air to be leaked into the annular space A.

The second end C of the outer member 3 is sealed by the ring seal 36 between the stationary product end structure 5 and the wall 19 of the outer member 3. The stationary product end structure 5 is sealed to the vapor discharge conduit 27 by a rotary pipe seal 80.

The vapor discharge conduit 27 preferably comprises an outer stationary section 81 rigidly secured to the

rotary pipe seal 80 and a rotating inner section 82 affixed to and rotating with the end plates 68, 69 on the inner tubular member 2.

Introducing Oxygen-Containing Gas

With reference to FIGS. 4 and 18, means B are provided for introducing an oxygen-containing gas, such as air, into the combustion zone F. More particularly, a slotted air discharge plenum 83 is provided in the space 74 between the second ends C of the tubular members 2,3. The plenum 83 is connected through a conduit 84 to a fan 85 which forces heated air through the plenum 83. The air is heated in heat exchangers 77 which recover heat from the hydrocarbon vapours withdrawn from the vaporization zone E. A direct fire burner 14 supplies additional heated air to the combustion zone F to supplement the heating provided by combustion. The plenum 83 is curved in the manner shown in the drawings to allow maximum contact of the heated air with the curtain of hot coked solids issuing from the inner tubular member 2. At the base of the plenum 83 a horizontal plenum nozzle 86 extends a small distance into the annular space A. This nozzle 86 supplies a high velocity stream of air along the annular space A to ensure that combustion continues along the extent of the combustion zone F.

Sand Solids Removal

The sand solids are removed from the annular space A at the first end B of the outer tubular member 3 by means generally indicated at 21 in FIGS. 2 and 4. The sand solids are dropped onto an enclosed conveyor belt 91 external of the outer member 3, where they are cooled and dampened with water. The cooled sands are conveyed through an air lock 87 to a disposal site. The steam resulting from cooling the hot sands, shown as stream K in FIG. 3, is combined with the steam and water vapor stream H from the preheat zone D and cooled in the previously disclosed manner.

Operation

To process oil sand feed material, the temperature in the apparatus is initially raised to about 1000° F. by introducing hot air at a temperature of about 1100° F. through the burner 14. The apparatus 1 is then purged with steam to remove oxygen therefrom. With the tubular members 2,3 rotating, whole oil sands solids, which may have been prescreened to remove large boulders, are conveyed into the preheat zone D through the feed chute 47. The high angle of attack of the advance plates 6, move the feed material quickly into the preheat zone D. In the preheat zone D, the feed material is heated, dehydrated and ablated as it is advanced therethrough by the inclined advance plates 6.

The heat is provided by heat transferred through the wall 16 of the inner tubular member 2 from the hot sand solids being dropped thereon in the surrounding annular space A. The oil sands are preferably preheated to a temperature of about 450° F. This heating causes a substantial reduction of the bitumen viscosity. As the tubular members 2,3 rotate, the feed material is repeatedly raised and dropped to create a cascading effect. The advance plates 6 and keying elements 6a are closely spaced to aid in this lifting action. This preheating and cascading of the whole oil sand in the preheat zone D causes lumps of oil sand to be ground and reduced in particle size. This combined action also conditions the feed material to release oversize debris such as rocks

from the lumps of oil sand. Oversize solids can thus be subsequently removed without losing a large quantity of oil sands.

The preheating step also vaporizes essentially all of the water associated with the oil sand feed material. The temperature in the preheat zone is maintained below about 700° F., to prevent any substantial amount of vaporization of the bitumen. The temperature in the preheat zone D is controlled by the residence time of the feed material therein. Residence time varies with the speed of rotation of the tubular member 2, 3 and the size and spacing of the advance plates 6 in the preheat zone D. Alternately the degree of lifting and dropping of the hot sand solids onto the outer surface 16 of the inner member can be varied. The water vapor and steam are withdrawn from the preheat zone D by the suction fan 22 and conduit 23 to the steam condensor 25.

By lowering the viscosity of the bitumen in the oil sand solids, the feed material is much less cohesive and more amenable to flow and to screening of oversize solids.

The steam and water vapor produced in the preheat zone D creates a slightly greater pressure in the preheat zone D than in the vaporization zone E. This provides an inert sealing atmosphere which, together with the partition wall 9, is operative to prevent significant movement of the gases between these two zones D, E.

It will be appreciated that if the amount of water present in the whole oil sand feed material is not sufficient to generate this steam barrier, water may be injected directly into the preheat zone D. Alternately the damper 24 on the steam removal means 7 can be closed so that the steam and water vapor are drawn into the vaporization zone E and removed with the hydrocarbon vapors.

At the second end 50 of the preheat zone D, oversize solids, including rocks and other debris or large lumps of oil sand solids, are separated and removed into the annular space A by the oversize removal means 8. Solids larger than the spacing of the curved bars 51 roll or slide along the bars 51 into the discharge chute 52 and are ejected into the annular space A. In this way, damage to the downstream equipment in the vaporization and combustion zones E, F is prevented.

Downstream of the oversize removal means 8, the de-rocked and preheated oil sand solids are passed through the openings 38 around the periphery of the partition wall 37 into the curved tubular members 55. Rotation of the inner tubular member 2 drops the solids into the vaporization zone E. Since the tubular members 55 are at least partially filled with the solids as the apparatus rotates, the solids cooperate with the wall 37 to restrict gas movement between the zones D, E.

In the vaporization zone E the preheated solids are further heated by introducing hot recycled solids through the recycle means 10 at the first end 88 of this zone. These hot solids recycled from the combustion zone F are typically at a temperature of about 1100°-1300° F. Rotation of the tubular members 2, 3 creates a gentle mixing or cascading action in the vaporization zone E to bring the overall temperature of the solids to about 900°-1000° F. Advance plates 6 and mixing spikes 6A positioned along the inner surface 16 of the inner tubular member 2 defining the vaporization zone E, advance and mix the solids toward the second end C of the inner member 2. The quantity of hot solids recycled is varied by adjusting the size of the outlet openings 66 provided by the recycle means 10. By vary-

ing the amount of solids recycled, the temperature in the zone can be controlled to optimize the degree of vaporization. It is desirable to try to reduce turbulence of the solids in the vaporization zone E to a minimum and thereby reduce the amount of fine particulates in the atmosphere.

The heat added in the vaporization zone E to the oil sand is sufficient to cause thermal cracking and vaporization of a portion of the bitumen and to produce a gaseous hydrocarbon product stream. The product stream is withdrawn from the vaporization zone E through the vapor discharge conduit 27 by the suction fan 26. The vapors are cleaned in one or more dust extractors 28 to remove the fine particulates entrapped therein. The vapors are then cooled and condensed to produce a liquid product. The non-condensable hydrocarbon vapors are further cooled and condensed to produce a gaseous hydrocarbon product.

After vaporizing at least a portion of the bitumen, a coke residue is left in association with the solid mineral particles. The coke residue and mineral solids are collectively referred to as coked solids.

At the second end 89 of the vaporization zone E, coked solids are transferred into the combustion zone F. As described previously, the means 12 for transferring the coked solids between these zones drops the solids in a curtain-like pattern. The curtain of falling particles is struck by a stream of high velocity hot air emitted from the plenum 83. The hot air supports combustion of at least a portion of the coke residue on the coked solids. By this combustion and supplemental heating with the burner 14, the overall temperature of the coked solids may be raised to about 1100°-1300° F.

The combustion-heated solids are advanced through the annular space A toward the first end B of the outer tubular member 3 by the advance plates 6. A high velocity hot air stream is projected along the annular space A to support combustion therealong. In addition, the combustion-heated solids are preferably lifted and dropped in the combustion zone F by lift elements 90. As shown in FIG. 7, the lift elements 90 are flat-type lifters. This lifting and dropping action provides maximum contact between the air and solids to maximize combustion.

The combustion gases and combustion-heated solids give up a portion of their heat, by convection and conduction, to the inner tubular member 2.

While it is believed that the majority of the combustion takes place in the annular space A, some combustion will also take place in the space 74 between the second ends C of the tubular members 2, 3. Thus the term "annular space" as used in the claims should be taken to refer both to the annular space between the walls 16, 19 of the tubular members 2, 3 and the space 74 between their second ends C. It is conceivable that the outer tubular member 3 could be extended to enlarge the space 74 if a larger combustion zone is desired.

A portion of the combustion-heated solids are recycled back from the annular space A into the vaporization zone E, to provide the hot recycle solids. As the tubular members 2, 3 rotate, the combustion-heated solids are advanced over and fall into the screened openings 63 to the compartments 60. Further rotation of the tubular members 2, 3 drops the hot recycle solids through the recycle tubes 62 into the vaporization zone E. The solids at least partially filling the recycle tubes 62 form a moving solids seal between the combustion and vaporization zones E, F to prevent significant gas

movement therebetween. Also, since the combustion-heated solids must pass over the screened openings 63 and over the weir plate 59a as they are advanced through the annular space A, the recycle means 10 are preferentially filled before the hot solids are advanced for disposal. This preferential filling of the recycle means 10 ensures a moving solids seal and a supply of hot recycle solids to the vaporization zone E even when the rate of feed material input is temporarily reduced.

That portion of the combustion-heated solids which is not recycled is advanced through the heat-transfer zone G. In the heat-transfer zone G these hot solids are repeatedly lifted and dropped onto the section 15 of the wall 16 of the inner tubular member 2 which defines the preheat zone E. In this way, waste heat from the hot solids is efficiently transferred to the feed material in the preheat zone E. By achieving a sliding solid-solid contact between the wall 16 of the inner member 2 and the hot solids, a desirable amount of heat is transferred. The lifting and dropping of the hot solids is achieved by the cup-faced lifters 44 affixed to the inner surface of the outer tubular member 3. This type of lifter has a large lifting capacity and actually lifts and drops the solids over the top of the rotating inner member 2 to contact the surface area of the inner tubular member 2.

The rate of solids movement through the heat-transfer zone G is relatively slow, as provided by the large spacing and small size of the advance plates 6 in this area. The slow rate of advance allows a maximum amount of heat to be recovered from the hot solids.

A suction fan 26 at the first end C of the outer tubular member 3 withdraws the combustion gases from the annular space A. The combustion gases are passed through a gas cleaning cyclone and wet extractor before being vented to an exhaust stack (not shown).

Solids from the heat transfer zone G, which include oversize solids and combustion-heated solids, are removed by dropping the solids from the first end B of the outer tubular member 3 onto the enclosed conveyor belt 91. The solids are cooled and dampened on the belt 91 by spraying them with a cooling fluid such as water. Steam produced in cooling the solids is directed through the conduit 82, past damper 93 and combined and removed with the steam from the preheat zone D. The dampened solids are conveyed through the air lock 87 to a disposal site. Alternately the solids may be cooled and dampened in the annular space A just prior to being removed from the processor 1. In some cases it may be desirable to cool and dampen the solids in both the annular space and exterior of the processor as is shown in FIG. 4. The cooling fluid may include thickened sludge withdrawn from the wet dust extractor as shown in FIG. 2.

As described above the gases produced in each of the preheat zone D, vaporization zone E and annular space A are substantially segregated from one another and removed from the apparatus 1 by separate gas removal means 7, 11 and 20 respectively. Preferably the pressures in each of these zones is controlled to maintain a pressure in the vaporization zone E which is less than the pressure in the preheat zone D and annular space A. Most preferably the pressures in the vaporization zone E, preheat zone D and annular space A are maintained at levels which ascend respectively. These pressures are preferably negative with respect to the atmospheric pressure outside the apparatus. This pressure control, as disclosed previously, is operative to maximize the removal of hydrocarbon vapors for recovery while mini-

mizing movement of hydrocarbon vapors into another zone and movement of combustion gases out of the apparatus.

A pilot plant unit processor was operated using Athabasca oil sand from Alberta. The processor was sized to handle 5 tons of feed material per hour. The processor had an inner tubular member having dimensions of 5.3' in diameter by 20' in length. The outer tubular member was 9' in diameter by 22' in length. Both the preheat and heat transfer zones were 12' in length while the vaporization and combustion zones were each 8' in length. The processor was rotated at about 3-6 R.P.M. most preferably at 4 R.P.M.

Retention times and temperatures for the various zones are shown in Table 1. A typical product analysis from a particular feed material is shown in Table 2.

TABLE 1

Zone	Retention Time	Temperature
Preheat Zone	4 min.	ambient to 450° F.
Vaporization Zone	2 min.	450° F.-950° F.
Combustion Zone	1.5 min.	950° F.-1080° F.
Heat-Transfer Zone	3 min.	1080° F.-500° F.
Final Cooling	<1 min.	500° F.-180° F.
Vapor Exit Temperature		970° F.
Combustion Gas Exit Temperature		520° F.

TABLE 2

(For Vapor Zone Temperature 900-1050° F.)

Feed Analysis	Product Analysis
Oil 9%, 7° API	Liquid Yield 60-72% of feed
Water 7.5%	API gravity 13° API
Host Sand and Clay 83.5%	Sediment and Water <2%
Sulphur 4.3%	Sulphur 3.7%
	Viscosity @ 20° C. 300 c.s.
	Coke Yield 18-30% of feed
	Crack Gas Yield (C ₄ -) 7-13% of feed

Due to processing considerations in the test unit auxiliary heating was needed to provide a substantial amount of the heat requirements. Approximately 3 gallons of fuel oil per ton of feed were burned in auxiliary burners.

As previously mentioned, the invention has only been practiced on oil sands. However, it is anticipated that other materials comprising host solids associated with hydrocarbons (such as oil shale) may also be processed by the invention.

It will be realized that oil shales and certain oil sands do not contain connate water. For this reason it may be necessary to inject water or an inert gas into the preheat zone D to maintain an inert atmosphere therein. Such materials may not contain oversize solids, in which case the oversize removal means 8 may be omitted.

While the present invention has been disclosed in connection with the preferred embodiment thereof, it should be understood that there may be other embodiments which fall within the spirit and scope of the present invention as defined in the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for recovering hydrocarbons from whole oil sand containing sand and clay solids in discrete and lump forms, water, bitumen and oversize solids using a processor which comprises rotatable inner and outer spaced tubular members, having first and

second ends, said outer member being sealed at its ends and said inner member being sealed at its first end, said inner member providing an open pre-heat zone at its first end and an open vaporization zone at its second end, said members combining to form an open substantially annular space having a combustion zone at its second end and a heat transfer zone at its first end,

said method comprising:

advancing the whole oil sand through the preheat zone and cascading it therein while heating it by heat transfer through the wall of the inner member to vaporize substantially all the water, without significant vaporization of hydrocarbons, and to effect size reduction of oil sand lumps;
separating oversize solids at the second end of the preheat zone and removing them into the annular space;
advancing the remaining preheated oil sand through the vaporization zone while further heating it by mixing it with hot recycled solids to vaporize and crack hydrocarbons and produce coked solids;
restricting gas movement between the preheat and vaporization zones;
withdrawing at least the greatest part of the water vapor and the greatest part of the hydrocarbon vapors separately from the processor;
transferring coked solids from the vaporization zone into the combustion zone while preventing significant gas movement between these zones in the course of the transfer;
burning at least part of the coke in the combustion zone to heat the solids;
withdrawing at least the greatest part of the combustion gases produced from the combustion zone;
advancing combustion-heated solids from the combustion zone to the heat-transfer zone;
recycling part of the combustion-heated solids into the vaporization zone to heat the preheated oil sand while preventing significant gas movement between the annular space and the vaporization zone in the course of the transfer;
advancing combustion-heated solids through the heat-transfer zone and lifting said solids and dropping them onto the wall of that portion of the inner member forming the preheat zone to transfer heat through said wall; and
removing combustion-heated and oversize solids from the processor as they complete their travel through the heat transfer zone.

2. The method as set forth in claim 1 comprising: maintaining the pressure in the vaporization zone at a level less than that in either the preheat zone or the annular space.

3. The method as set forth in claim 1 comprising:

maintaining the pressures in the vaporization zone, preheat zone, and annular space at levels which ascend respectively.

4. A method for recovering hydrocarbons from host solids containing hydrocarbons, using a processor which comprises rotatable inner and outer spaced tubular members, having first and second ends, said outer member being sealed at its ends and said inner member being sealed at its first end, said inner member providing an open preheat zone at its first end and an open vaporization zone at its second end, said members combining to form an open substantially annular space having a combustion zone at its second end and a heat transfer zone at its first end,

said method comprising:

advancing the host solids through the preheat zone and cascading it therein while heating it by heat transfer through the wall of the inner member to vaporize substantially all the water, without significant vaporization of hydrocarbons;
advancing the preheated host solids through the vaporization zone while further heating it by mixing it with hot recycled solids to vaporize and crack hydrocarbons and produce coked solids;
restricting gas movement between the preheat and vaporization zones with an apertured baffle;
withdrawing at least the greatest part of the water vapor and the greatest part of the hydrocarbon vapor separately from the processor;
transferring coked solids from the vaporization zone into the combustion zone while preventing significant gas movement between these zones in the course of the transfer;
burning at least part of the coke on the coked solids in the combustion zone to heat the solids and withdrawing combustion gases produced from the processor;
advancing combustion-heated solids from the combustion zone to the heat-transfer zone;
recycling part of the combustion-heated solids into the vaporization zone to heat the preheated host solids while preventing significant gas movement between the annular space and the vaporization zone in the course of the transfer;
advancing combustion-heated solids through the heat-transfer zone and lifting said solids and dropping them onto the wall of that portion of the inner member forming the preheat zone to transfer heat through said wall;
removing combustion-heated solids from the processor as they complete their travel through the heat transfer zone; and
maintaining the gaseous atmospheres in the preheat and vaporization zones and the annular space substantially segregated one from another by said withdrawing and restricting steps.